# The Treatment of Steel

Bartlett & Company
The Orr Press
New York

# Treatment of Steel

A Compilation from Publications of
the Crescent Steel Company on

Annealing, Forging, Hardening and Tempering
n the use of Furnaces; also a chapter on
Hardening and Tempering from a work
by George Ede, Woolwich
Arsenal, England



rucible Steel Company of America

Pittsburgh, Pennsylvania, U. S. A.

1902

# Preface to the Third Edition

"Steel," as Arnold well expresses it, "is a marvelously complex material, containing always more or less of the following elements in addition to iron: carbon, silicon, manganese, sulphur and phosphorus. Besides these constituents, there may be present by design or accident the following:—tungsten, chromium, aluminium, nickel, copper, arsenic," . . . and, we may add, molybdenum.

"In addition to these elements, steel contains the gaseous bodies, hydrogen and nitrogen, and sometimes oxygen."

Altogether, as Dr. Dudley points out, there are "fifteen or twenty elements occurring in and affecting the quality of iron and steel," while Carnot and Goutal call attention to the fact that through purely chemical methods four conditions of carbon have been detected:—"graphite or free crystallized carbon; graphitic carbon or temper carbon; the carbon of the carbide of iron (cement carbon) and hardening carbon."

The microscope reveals four constituents in carbon steel:—"ferrite or nearly pure malleable iron; sorbite or iron slightly carburetted; pearlite, composed of alternate plates of ferrite or sorbite and of the carbide $Fe_3C$., and cementite or the carbide $Fe_3C$.," while, forming the bulk of hardened steel, "are three other constituents, martensite, troostite and austensite."

"Of all the elements connected with steel," Arnold says, "carbon is by far the most important: as the blood is the life, so is the carbon the steel"—truly a wondrous metal, steel.

Ridsdale, in the *Journal* of the British Iron and Steel Institute, tabulates twenty-four faults, under seven different types, observed by him in steel, and in tracing the probable causes he charges seven of these to the maker, nine to the user, and one to both.

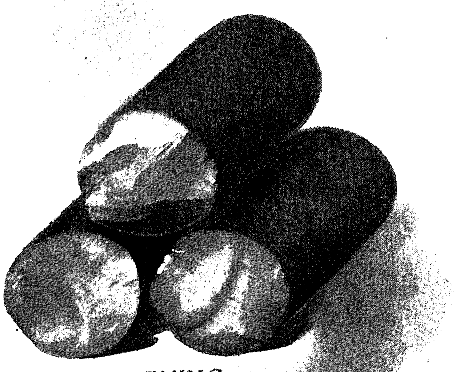
Treatment, therefore, and particularly heat treatment, is closely related to the behavior and value of steel. This third edition of "The Treatment of Steel" is issued at the request of many with the hope that it will be accepted as an effort to assist in overcoming difficulties connected with the working of a metal so complex; if some find in it nothing that is new, others may be able to select something that will be of interest and profit.

Crucible Steel Company of America

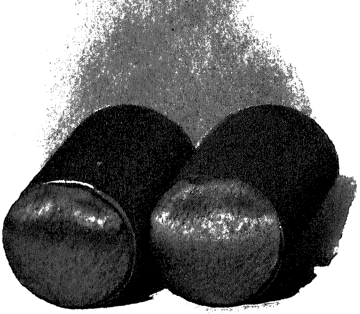
A. L. B.

July, 1902

BURNT



REFINED BY HARDENING



NATURAL BAR

# The Treatment of Steel

## Annealing Steel

Owing to the fact that the operations of rolling or hammering steel make it very hard, it is frequently necessary that steel should be annealed before it can be conveniently cut into required shapes for tools.

Annealing or softening is accomplished by heating steel to a red heat and then cooling it very slowly, to prevent it from getting hard again.

The higher the degree of heat the more the steel will be softened, until the limit of softening is reached when the steel is melted.

It does not follow that the higher a piece of steel is heated the softer it will be when cooled, no matter how slowly it may be cooled; this is proved by the fact that an ingot is always harder than a rolled or hammered bar made from it.

Therefore, there is nothing gained by heating a piece of steel hotter than a good bright cherry red; on the contrary, a higher heat has several disadvantages:

FIRST. If carried too far, it may leave the steel actually harder than a good red heat would leave it.

SECOND—If a scale is raised on the steel, this scale will be harsh, granular oxide of iron, and will spoil the tools used to cut it. It often occurs that steel is scaled in this way, and then because it does not cut well, it is customary to heat it again, and hotter still, to overcome the trouble; while the fact is, that the more this operation is repeated, the harder the steel will work, because of the hard scale and the harsh grain underneath.

THIRD—A high scaling heat, continued for a little time, changes the structure of the steel, destroys its crystalline property, makes it brittle, liable to crack in hardening, and impossible to refine.*

Again, it is a common practice to put steel into a hot furnace at the close of a day's work, and leave it there all night. This method always gets the steel too hot, always raises a scale on it, and worse than either, it leaves it soaking in the fire too long; and this is more injurious to steel than any other operation to which it can be subjected.

A good illustration of the destruction of crystalline structure by long-continued heating may be had by operating on chilled cast-iron.

If a chill be heated red hot and removed from the fire as soon as it is hot, it will, when cold, retain its peculiar crystalline structure; if now it be heated red hot, and left at a moderate red for several hours; in short, if it be treated as steel often is, and be left in a furnace over night, it will be

*"In high-carbon tool steels a prolonged high heat may also throw the carbon out of its proper combination with the iron, giving a coarse grayish or blackish fracture. Such a steel will harden, but can never have the strength of one properly treated. It will break with a straight, 'dead' fracture and be lacking in toughness." *E. L. French.*

found, when cold, to have a perfect amorphous structure, every trace of chill crystals will be gone, and the whole piece will be non-crystalline gray cast-iron. If this is the effect upon coarse cast-iron, what better is to be expected from fine cast-steel ?

A piece of fine tap steel after having been in a furnace over night will act as follows :

It will be harsh in the lathe and spoil the cutting tools.

When hardened it will almost certainly crack ; if it does not crack it will have been a remarkably good steel to begin with. When the temper is drawn to the proper color and the tap is put into use, the teeth will either crumble off or crush down like so much lead.

Upon breaking the tap the grain will be coarse and the steel brittle.

To anneal any piece of steel, heat it red hot; heat it *uniformly* and heat it *through*, taking care not to let the ends and corners get too hot.

As soon as it is hot take it out of the fire, the sooner the better, and cool it as slowly as possible. A good rule for heating is to heat it at so low a red that when the piece is cold it will still show the blue gloss of the oxide that was put there by the hammer or the rolls.

Steel annealed in this way will cut very soft; it will harden very hard, without cracking, and when tempered it will be very strong, nicely refined and will hold a keen, strong edge.

# Heating Steel

Owing to varying instructions on a great many different labels, we find at times a good deal of misapprehension as to the best way to heat steel; in some cases this causes too much work for the smith, and in other instances disasters follow the act of hardening.

There are three distinct stages, or times of heating:

FIRST—For forging.

SECOND—For hardening.

THIRD—For tempering.

The first requisite for a good heat for forging is a clean fire and plenty of fuel, so that jets of hot air will not strike the corners of the piece; next, the fire should be regular, and give a good uniform heat to the whole part to be forged. It should be keen enough to heat the piece as rapidly as may be, and allow it to be thoroughly heated through, without being so fierce as to overheat the corners.

The trouble in the forge fire is usually uneven heat, and not too high heat. Suppose the piece to be forged has been put into a very hot fire, and forced as quickly as possible to a high yellow heat, so that it is almost up to the scintillating point. If this be done, in a few minutes

the outside will be quite soft and in nice condition for forging, while the middle parts will be not more than red hot. The highly heated soft outside will have very little tenacity; that is to say, this part will be so far advanced toward fusion that the particles will slide easily over one another, while the less highly heated inside parts will be hard, possessed of high tenacity, and the particles will not slide so easily over each other.

Now let the piece be placed under the hammer and forged, and the result will be as shown in Fig. 1.

The soft outside will yield so much more readily than the hard inside, that the outer particles will be torn asunder, while the inside will remain sound, and the piece will be pitched out and branded "burned."

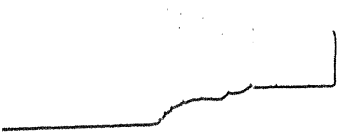


Fig. 1

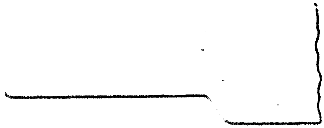


Fig. 2

Suppose the case to be reversed and the inside to be much hotter than the outside; that is, that the inside shall be in a state of semi fusion, while the outside is hard and firm.

Now let the piece be forged and we shall have the case as shown in Fig. 2. The outside will be all sound and the whole piece will appear perfectly good until it is cropped, and then it is found to be hollow inside, and it is pitched out and branded "burst."

In either case, if the piece had been heated soft all through, or if it had been only red hot all through, it could have been forged perfectly sound and good.

If it be asked, why then is there ever any necessity for smiths to use a low heat in forging, when a uniform high heat will do as well, we answer:

In some cases a high heat is more desirable to save heavy labor, but in every case where a fine steel is to be used for cutting purposes, it must be borne in mind that *very heavy forging* refines the bars as they slowly cool; and if the smith heats such refined bars until they are soft, he raises the grain, makes them coarse, and he cannot get them fine again unless he has a very heavy steam hammer at command and knows how to use it well.

In following the above hints there is a still greater danger to be avoided: that is incurred by letting the steel lie in the fire after it is properly heated. When the steel is hot through it should be taken from the fire immediately and forged as quickly as possible.

"Soaking" in the fire causes steel to become "dry" and brittle, and does it more injury than any bad practice known to the most experienced.

By observing these precautions a piece of steel may always be heated safely, up to even a bright yellow heat, when there is much forging to be done on it; and at this heat it will weld well.

The best and most economical of welding fluxes is clean, crude borax, which should be first thoroughly melted and then ground to fine powder. Borax prepared in this way will not froth on the steel, and one-half of the usual quantity will do the work as well as the whole quantity unmelted.

After the steel is properly heated it should be forged to shape as quickly as possible, and just as the red heat is leaving the parts intended for cutting edges these parts

should be refined by rapid light blows, continued until the red disappears.

For the second stage of heating for hardening great care should be used, first, to protect the cutting edges and working parts from heating more rapidly than the body of the piece; next, that the whole part to be hardened be heated uniformly through, without any part becoming visibly hotter than the other. A UNIFORM heat, as low as will give the required hardness, is the best for hardening.

BEAR IN MIND, that for every VARIATION OF HEAT which is great enough to be seen there will result a VARIATION IN GRAIN, which may be seen by breaking the piece, and for every such variation in temperature there is a very good chance for a CRACK to be seen. Many a costly tool is ruined by inattention to this point.

The effect of TOO HIGH HEAT is to OPEN THE GRAIN, to make the steel COARSE.

The effect of an IRREGULAR heat is to cause IRREGULAR grain, IRREGULAR strains, and CRACKS.

As soon as the piece is properly heated for hardening it should be promptly and thoroughly quenched in plenty of the cooling medium, water, brine or oil, as the case may be.

An abundance of the cooling bath, to do the work quickly and uniformly all over, is very necessary to good and safe work.

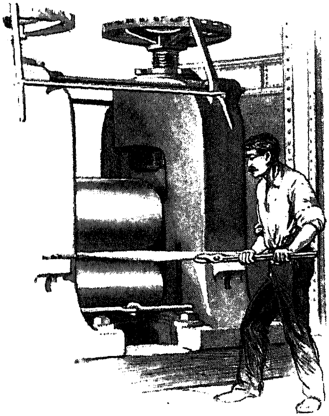
To harden a large piece safely a running stream should be used.

Much uneven hardening is caused by the use of *too small* baths.

For the third stage of heating; to temper, the first important requisite is again UNIFORMITY. The next is time;

the more slowly a piece is brought down to its temper, the better and safer is the operation.

When expensive tools, such as taps, rose cutters, etc., are to be made, it is a wise precaution, and one easily taken, to try small pieces of the steel at different temperatures, so as to find out how low a heat will give the necessary hardness. The lowest heat is the best for any steel, the test costs nothing, takes very little time, and very often saves considerable losses.



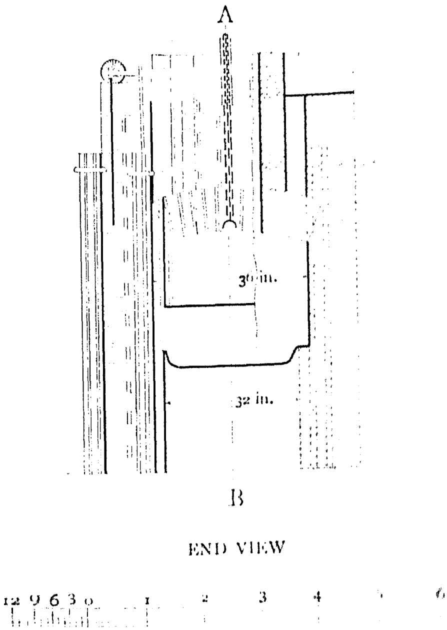
# Furnaces

On the following pages we present sketches of a cheap and handy furnace for use in a blacksmith shop, adapted especially for heating steel, and more particularly for heating steel for hardening.

The furnace is so simple that the sketches need no explanation; for binders, ten pieces of old rail about six feet long with one end set in the ground and the tops tied by ¾-inch rods are all that is necessary, with a piece of iron about 3 x ¾ inch running around near the top, and set in flush with the bricks.

The distinctive features of this furnace are the fire bed and a good damper on the stack. In an experience of many years we have found nothing better than the Tupper grate-bar with ½-inch openings. These bars set in as shown make a level, permanent bed, and give an evenly distributed supply of air to the fuel. In such a furnace as this one set of bars will last for years and remain level.

While on the subject of grate-bars we may as well say that the satisfactory and safe working of this furnace would be entirely defeated by any attempt to use either square




END VIEW

Scale: $\frac{5}{16}$ = 1 foot.

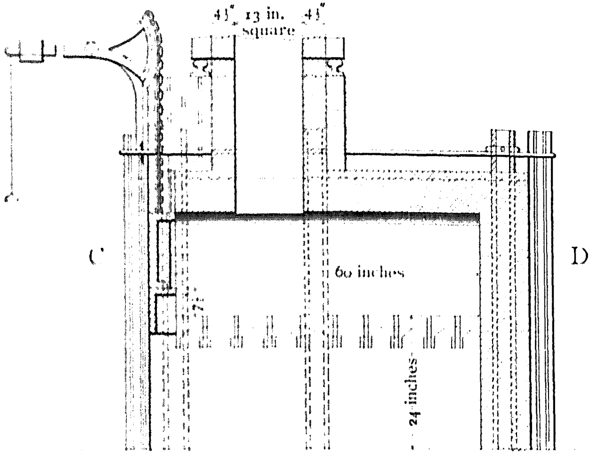
Stack 15′ to 20′ high

wrought-iron bars or ordinary straight cast-iron bars. Such bars always warp, get pushed out of place, and allow a rush of air through at one place and no air at another. This causes hot and cold places in the furnace and produces

uneven heating, which is the chief source of cracking in hardening, and also the air rushing through the large holes will burn the steel. A bar must be used which will remain level and in its place, and the smaller and more numerous the openings are the better will be the result.

Clean, hard coke is the only proper fuel for such a furnace and for such work. The furnace should be filled full up to

SECTION A B




the fore plate—or better, a little higher—with coke in pieces no larger than an ordinary man's fist, but the smaller the better.

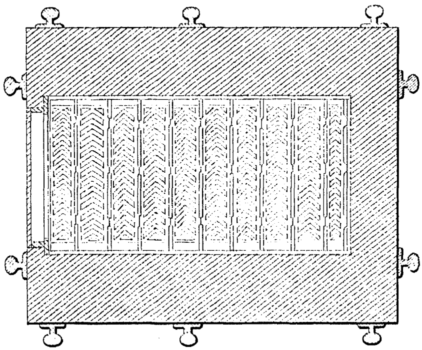
When it is used for heating for forging purposes the damper may be left high enough to run the furnace as hot as may be required if necessary, a welding heat can be obtained.

When used for hardening, the furnace should be got as hot as is needed before the steel is put into it—then

when the steel is put in, the damper should be dropped down tight.

The door, which is 12 inches high and 24 inches wide, should be nicely balanced by a lever and weight, with a rod in a handy place so that the operator can pull it up easily and turn over his pieces from time to time, so as to get his heat perfectly uniform.

In the clear gas of a coke fire the whole interior of a furnace can be seen easily, and every piece can be watched as it ought to be. Time, care, watchfulness and absolute uniformity of heat are the essentials necessary for success in hardening steel.



SECTION C D

Every large shop should have such a furnace, and should have one man trained to its use, to do the hardening and tempering for the whole shop. Such a furnace in the hands of a careful man in any railroad shop in the country would pay for itself every year and save the man's wages besides.

The furnace will consume very little coke at any time, and when not in use, with the damper down, it will stay hot a long time and waste the coke but a trifle.

There is no more absurd nor wasteful system than that of requiring a smith at his anvil to harden and temper his work. His fire is not fit to heat in, to

begin with, and he never has time to do his work properly, if it were.

From such a furnace as is here described we harden all sorts of tools, taps, small dies, large rolls, rotary shear knives, and shear knives as large as five feet long, which is the whole length of the furnace.

The steel which is hardened and tempered best is the finest in the grain and the strongest. The best way to test both grain and strength is to hammer out a piece to about $1\frac{1}{4} \times \frac{1}{8}$ inch, a foot or so in length, harden it at a heat which is considered nearly right for the particular piece, and temper to a high blue, or pigeon wing, and when cold to break it off in little pieces with a hand hammer. A little practice will soon enable a man to determine if he heated the piece to just the right point in hardening. A fine, silky grain will show this, and the hammer and file, respectively, will tell whether the tempering has made the stock tough enough and of the proper degree of hardness for the work the steel must do.

In every shop there are plenty of worn-out tools of all sorts in the scrap heap; the temperer should be allowed to spend all of his leisure time in hammering these out and testing them as above. The steel will cost nothing, and the knowledge gained will pay for the time over and over again. We say to our friends again that if you will heat even the finest steel in dirty slack fires you will get dirty coats of sulphurous oxides on it, and no good results.

The cost of such a furnace as we have described is about one hundred and fifty dollars.

# Effects of Heat Upon Steel

We give herewith a description of the method by which any worker in steel should be able to obtain a satisfactory illustration of the effect of heat upon steel.

DESCRIPTION—Take a bar of steel of ordinary size, say about 1 inch by ½, and heat 6 or 8 inches of one end to a low red heat, and nick the heated part all around the bar at intervals of ½ to ¾ of an inch, until eight or nine notches are cut. Next place the end of the bar in a very hot fire and heat it white hot until it scintillates at the extreme end, leaving the other parts enough out of the fire to heat them only by conduction. Let the end remain in the fire until the last piece nicked is not quite red hot, and the next to the last barely red hot.

Now, if the pieces be numbered from 1 to 8, commencing at the outer end, No. 1 will be white or scintillating hot, No. 2 will be white hot, No. 3 will be high yellow hot, No. 4 will be yellow or orange hot, No. 5 will be high red hot, No. 6 will be red hot, No. 7 will be low red hot, No. 8 will be black hot.

As soon as heated, let the bar be quenched in cold water and kept there until quite cold. After cooling, the bar should be carefully wiped dry, especially in the notches. An examination by the file will reveal the following, if high steel has been used:

No. 1 will scratch glass, Nos. 2, 3 and 4 excessively hard, Nos.

5 and 6 well hardened, No. 7 about hard enough for tap steel, No. 8 not hardened.

Now break off the pieces over the corner of the anvil. They should be caught in a clean keg or box, to keep the fractures clean and bright.

No. 1 will be as brittle as glass, No. 2 will be nearly as brittle as glass, Nos. 3, 4 and 5 will break off easily, each a little stronger than the other, Nos. 6 and 7 will be very strong, and much stronger than No. 8, or the bar unhardened.

Place the pieces in the order of their numbers fitting the fractures, then up-end each one, beginning with No. 1 and following with each in the order in which they lie, and the result will be fractures which any ordinary skilled eye can appreciate, each differing from the other.

No. 1 will be coarse, yellowish cast, and very lustrous; No. 2 will be coarse and not quite so yellow as No. 1; No. 3 will be finer than 1 or 2, and coarser than No. 8, and will have fiery luster; No. 4, like No. 3, not quite so coarse, yet coarser than No. 8; No. 5 will be about the same size grain as No. 8, but will have fiery luster; No. 6 will be much finer than No. 8, will have no fiery luster, will be hard nearly through and very strong. This is what is called *refining* by hardening. No. 7 will be refined and hard on the corners and edges, and coarser and not hard in the middle. This is about the right heat for hardening taps, milling tools, etc., the teeth of which will be amply hard, while there will be no danger of cracking the tool.* No. 8 illustrates the original grain of the bar.

* Note by A. L. B.—On the other hand it is contended by one of our writers that the temperature indicated by No. 6 is right for *all*

In nine cases out of ten the bar will crack along the middle to the refined piece. In tests made we have had the crack show plainly, but we have never known this crack to extend *into* the refined piece, although we have repeated the experiment many times. We learn from this experiment the following:

FIRST—(*a*) Any difference in temperature sufficiently great to be seen by the color will cause a corresponding

hardened work, including taps, reamers and milling cutters, and that a superficial hardening, such as is shown in No. 7, is fatal to the class of tools mentioned, because they are almost certain to crack in the hardening process. It must be borne in mind, however, that the hardening is effected upon flat surfaces in the series of fractures shown, whereas, in the case of toothed tools, the small projections are acted upon by the chilling medium and are hardened through, while the hardening also extends into the body of the tool. It is true that No. 6 is the ideal condition for all hardened steel, wherever that condition can be attained, but the degree of heat that, in a tap of considerable size, would carry the hardening through to the center, would overheat the projecting teeth unless very carefully applied. And such overheat would mean an exchange of the structure of No. 7 for a combination of the coarser grain of No. 5 (in the projections) with the refined structure of No. 6 (in the body), a variation in grain which would result in cracking and crumbling.

A beautiful exemplification of superficial hardening as shown in No. 7, is that of long stay bolt taps when heated for hardening in iron pipes in which the tool is kept turning while the heat is being applied through the walls of the pipe. A tap so treated is soft enough in the center to be drilled, while the teeth are well hardened and refined.

The statement in the text may, perhaps, be made clearer if we add: Heat the tool evenly through without letting the cutting parts get hotter than the refining heat, shown by No. 6, and these parts will be well hardened while the body of the tool will be hard enough.

difference in the grain. (*b*) This variation in grain will produce internal strains and cracks.

SECOND—Any temperature so high as to open the grain so that the hardened piece will be coarser than the original bar will cause the hardened piece to be brittle, liable to crack, and to crumble on the edges in use.

THIRD—A temperature high enough to cause a piece to harden through, but not high enough to open the grain, will cause the piece to *refine*, to be stronger than the untempered bar, and to carry a tough, keen, cutting edge.

FOURTH—A temperature which will harden and refine the corners and edges of a bar, but which will not harden the bar through, is just the right heat at which to harden taps, rose-bitts and complicated cutters of any shape, as it will harden the teeth sufficiently without risk of cracking, and will leave the mass of the tool soft and tough, so that it can yield a little to pressure and prevent the teeth tearing out.* These four rules are general, and apply equally well to any quality of steel or to any temper of steel.

Steel which is so mild that it will not harden in the ordinary acceptance of the term will show differences of grain corresponding to variations in temperature.

To restore any of the first seven pieces shown to the original structure† as shown in No. 8, it is only necessary to heat it through to a good red heat, not to a high red, allow

* See foot note page 21.

† Note by A. L. B.—The author means physical structure. As to his opinion of the value of at least two of the pieces, say, Nos. 1 and 2, when so restored, see his final paragraph on next page. Also compare page 50.

it to stay at this temperature for ten minutes to thirty minutes, according to the size of the piece, and then to cool slowly. If upon the first trial the restoration should be found incomplete, and the piece upon being fractured should still show some fiery grains, a second heating continued a little longer than the first would cause a restoration of fracture. This property of restoration is not peculiar to any steel, and its performance requires no mysterious agencies beyond those given above.

It should be distinctly borne in mind that a piece restored from overheating is never as good as it would have remained if it had not been abused, and we strongly advise that no occasion should ever be given for the use of this process of restoration except as an interesting experiment. The original and proper strength of fine steel can never be FULLY RESTORED after it has once been destroyed by overheating.

# On Temper of Steel

The word temper, as used by the steel maker, indicates the amount of carbon in steel; thus, steel of high temper is steel containing much carbon; steel of low temper is steel containing little carbon; steel of medium temper is steel containing carbon between these limits, etc. Each number of our carbon circular represents a temper, and besides these numbers we use intermediate ones, amounting to some twenty in all. As the temper of steel can only be observed in the ingot, it is not necessary to the needs of the trade to attempt any description of the mode of observation, especially as this is purely a matter of education of the eye, only to be obtained by years of experience.

The act of *tempering* steel is the act of giving to a piece of steel, after it has been shaped, the hardness necessary for the work it has to do. This is done by first hardening the piece, generally a good deal harder than is necessary, and then toughening it by slow heating and gradual softening until it is just right for work.

A piece of steel properly tempered should always be finer in grain than the bar from which it was made. If it is necessary, in order to make the piece as hard as is required, to heat it so hot that after being hardened it will be

as coarse or coarser in grain than the bar, then the steel itself is of too low temper for the desired work. In a case of this kind the steel maker should at once be notified of the fact, who should immediately correct the trouble by furnishing higher steel.

If a great degree of hardness is not desired, as in the case of taps, and most tools of complicated form, and it is found that at a moderate heat the tools are too hard and are liable to crack, the smith should first use a lower heat in order to save the tools already made, and then notify the steel maker that his steel was too high, so as to prevent a recurrence of the trouble. In all cases where steel is used in large quantities for the same purpose, as in the making of axes, springs, forks, etc., there is very little difficulty about temper, because, after one or two trials, the steel maker learns what his customer requires, and can always furnish it to him.

In large, general works, however, such as rolling-mills, nail factories, large machine works, or large railroad shops, both the maker and worker of the steel labor under great disadvantages from want of a mutual understanding.

The steel maker receives his order and fills it with tempers best adapted to general work, and the smith usually tries to harden all tools at about the same heat. The steel maker is right, because he is afraid to make the steel too high or too low, for fear it will not suit, and so he gives an average adapted to the size of the bar.

The smith is right, because he is generally the most hurried and crowded man about the establishment. He must forge a tap for this man, a cold nail knife for that one, and a lathe tool for another, and so on; and each man is in a hurry.

Under these circumstances he cannot be expected to stop and test every piece of steel he uses, and find out exactly at what heat it will harden best, and refine properly.

He needs steel that will all harden properly at the same heat, and this he usually gets from the general practice among steel makers of making each bar of a certain temper, according to its size.

But if it should happen that he were caught with only one bar of, say, inch-and-a-quarter octagon, and three men should come in a hurry, one for a tap, another for a punch, and another for a chilled roll plug, he would find it very difficult to make one bar of steel answer for all of these purposes, even if it were of the very best quality, and the chances are that he would make one good tool and two bad tools.

There is a perfectly easy and simple way to avoid all of this trouble; and that is, to write after each size the purpose for which it is wanted, as for instance: Track tools, smith tools, lathe tools, taps, dies, cold nail knives, cold nail dies, hot nails, hot or cold punches, shear knives, etc. This gives very little trouble in making the order, and it is the greatest relief to the steel maker. It is his delight to get hold of such an order, for he knows that when it is filled he will hardly ever hear a complaint.

Every steel maker worthy of the name knows exactly what temper to provide for any tool, or if it is a new case, one or two trials are enough to inform him, and as he always has all of his twenty odd tempers on hand, it is just as easy and far more satisfactory to both parties to have it made right as to have it made wrong.

A Sheffield manufacturer calls attention to this same experience, and very truthfully remarks:

"For many purposes, indeed, temper is of more importance than quality. Nothing is more common than for steel to be rejected as bad in quality, because it has been used for a purpose for which the temper was unsuitable. We may divide consumers of steel into three classes: First, those who use their own judgment of what percentage of carbon they require, and instruct the manufacturer to send them steel of a specified temper; second, those who leave the selection of the temper to the judgment of the manufacturer, and instruct him to send them steel for a specified purpose; and third, those who simply order steel of a specified size, leaving the manufacturer to guess for what purpose it is required. It cannot too often be reiterated of how much importance it is, when ordering steel, to state the purpose for which it is going to be used."

And again:

"You may depend upon it there is nothing so dear as cheap steel. It must be more economical to put five shillings' worth of labor upon steel that costs a shilling, to produce a tool that lasts a day, than to put the same value of labor upon steel that costs only ninepence, to produce a tool that lasts only half a day. I am sure that the system adopted by some large consumers of buying tool steel by tender is one which in too many cases defeats the object for which it was instituted, and, by lessening the price, and consequently deteriorating the quality, causes the steel bill to be lessened at the cost of the labor bill, so that extravagance instead of economy is the result. In fact, it is an illustration of the proverb about being penny wise and pound foolish."

# Why Does Steel Harden?

By W. Metcalf, C. E.

The inquiry has been pursued diligently by Prof. John W. Langley and ourselves for the past five years, and has been directed exclusively to the gathering of facts, so that as yet we have not even a theory to offer. The inquiry may be divided as follows:

1. The physical structure of steel.

2. The chemical composition.

3. The variations of structure and physical properties due to—

*a.*—Cooling from fusion.

*b.*—Effect of work, either by rolling or hammering.

*c.*—Effect of temperature, and of changes from one temperature to another, as shown by slow cooling or rapid cooling.

4. A statement of the various theories of hardening.

5. Some practical conclusions for workers of steel.

1. The physical structure of steel.

In this paper it is to be understood that reference is made only to cast-steel.

Steel is crystalline in structure. The size, color and form of the crystals, when steel is allowed to cool without hindrance from a state of fusion, are governed by its chemical

# On Gauges

In consequence of the absurdities and anomalies existing in our present system of gauges, we recommend the use of the inch as a unit of measurement.

There are in use at the present time three standard gauges.

It may be possible to make one gauge to any of these standards which shall be so accurate as to defy the detection of an error, and with the same care it may be possible to make a thousand such gauges; but every mechanic, and every person accustomed to making accurate measurements of the best work, knows that it is simply impossible to obtain absolute accuracy in such pieces of work when produced in large quantities, and it is impossible *commercially*, on account of the cost.

We therefore recommend the use of the micrometer sheet metal gauge, which measures thousandths of an inch very accurately, and a skilled mechanic can determine even a quarter of a thousandth with precision.

constitution, and are mainly influenced by the quantity of carbon present.

2. The chemical composition of steel.

Steel is mainly an alloy, compound or mixture of iron and carbon.

Exactly which of these it may be, or whether it is a combination of two or of all three of these conditions, it is difficult to say.

Other elements, as silicon, phosphorus, sulphur, manganese, and so on, are as yet present only by sufferance, and generally it is well known that steel is better without any of them.

The range of carbon in commercial steel may be said to be from about .05 per cent. to 1.75 or 2 per cent., but for some purposes of this inquiry we may look at several properties of cast-iron as being useful to throw light on the subject.

3. The variations of structure and physical properties due to—

*a.*—Cooling from fusion—as affected by chemical composition, temperature, and rate of cooling.

The structure of steel, and of cast-iron, as shown in a fresh fracture of the ingot in one case, or the pig in the other, is remarkable as always indicating the quantity of carbon present, the temperature at which the metal was poured, and the rate of cooling.

As the observation of these phenomena furnishes material for the study of a lifetime, and as they cannot be described properly without the objects themselves, only a few well-known facts will be mentioned, for use in the latter part of this paper. Cast-iron, when poured into iron moulds, hardens just as steel does when quenched in water; this is known as "chilling."

A chill is of silvery white color, bright luster and consists of elongated crystals generally normal lengthwise to the surface of the mould.

If iron contains little or no silicon, it will chill very deep, or entirely through the mass in small castings.

If much silicon be present it will not chill at all.

If a hard chill—for instance in a hammer die say two inches thick of chill, be brought to a red heat, removed from the fire at once and allowed to cool slowly, it will, when broken, be found to be softened, but it will retain the marked crystalline form of the chill. This is analogous to tempered steel.

If the same chill be heated red, and kept red hot for several hours, and then cooled slowly, it will be found upon breaking to be an entirely amorphous gray cast-iron; every trace of the elongated crystals of the chill will have disappeared.

This is analogous to annealed steel. This experiment is a striking example of iron and combined carbon in the one case, and of iron and graphitic carbon in the other case, as these conditions are commonly understood.

This observation is useful in understanding similar changes which occur in steel under the similar conditions of hardened, tempered and annealed steel.

Steel when cast is almost invariably poured into iron moulds, and the study of fractured ingots is very necessary to the steel maker; but as the ingots very rarely go into the hands of the consumer without previous manipulation, it is hardly necessary to consume time in discussing the characters of the fractures, especially as it requires the actual presence of the ingots to make the description at all intelligent.

It is sufficient to say that we have here an unvarying record of the completeness or incompleteness of the fusion, of the rate and temperature of the pouring, and of the chemical character of the steel, especially as it relates to carbon.

*b.* Effect of work, either by hammering or rolling.

Steel, when heated and hammered or rolled from the ingot, has its specific gravity largely increased, its strength is greatly increased, and its grain is made very fine and uniform; this is called "hammer refining," to distinguish it from the refining due to hardening.

An eminent Russian engineer has illustrated this hammer refining beautifully by comparing the hot steel to a certain solution of a salt.

If the solution be allowed to precipitate slowly and undisturbed, very large crystals will be formed, but if it be violently shaken, the crystallization is hastened and very fine crystals are formed.

So if steel be heated quite hot, but not so as to burn it, and be allowed to cool very slowly, it will form in very large, bright crystals and be very friable; but if as soon as it is hot it be taken to a heavy hammer and be thoroughly hammered by rapid and powerful blows at first, and then by lighter blows until it is of the required shape, it will be found to be very fine in grain and very strong.

Therefore, a high softening heat is consistent with good work in forging.

*c.* Effects of temperature, and of changes from one temperature to another, as shown by slow cooling or rapid cooling.

The effect of heating steel which has been hammered or rolled is to increase the size of the crystals or grain, in proportion to the temperature, and to reduce the specific gravity. There is an apparent or real exception to this increase in size of grain in steel which has been hardened from the proper temperature to produce what is known as "refining."

In this case the grain is much finer than in the bar, and in this condition any piece of hardened and tempered steel is at its best.

As this refining temperature varies with every different quantity of carbon, no rule can be laid down for determining it; it must be found by actual trial.

But there is no exception to the matter of specific gravity. The specific gravity of refined steel is less than that of the bar, although the grain is much finer. If steel be heated and cooled slowly it will be softened; that is, annealed.

If it be heated very hot, say to bright yellow, or kept hot a long time, and then cooled slowly, it will still be annealed, but it will be harsh and gritty, will not cut well, and will neither refine well when hardened nor hold a good edge when tempered. The cause of this will be obvious if we remember the experiment of the annealed chill mentioned in the earlier part of this paper. If steel be heated to different degrees, as red, bright red, orange, lemon or bright yellow color, and quenched, it will be found to be harder, more brittle, and coarser in the grain for each increasing degree of heat, after the "refining" heat has been passed. Below the "refining" heat there will be no useful degree of hardening, and the grain will be variable.

If any piece of hardened steel be heated red hot, and cooled slowly, it will be softened, the grain of the steel

will return to its original appearance in the bar, and its specific gravity will be restored to the specific gravity of the bar.

This fact should put a quietus upon all quack nostrums for "restoring burnt steel."

If a piece of steel containing little carbon be alternately hardened and heated and re-hardened a number of times, it will vary in volume, but will not sustain regular increases of volume.

If steel of moderately high carbon be repeatedly hardened it will continue to increase in volume until ruptured. This will be illustrated by table No. 5.

Some years ago twelve ingots were selected by numbers, and analyzed to determine the accuracy of ocular inspection, and were afterward experimented upon in following up the search for facts in regard to the cause of "hardening."

The specific gravities of these ingots were determined, and the results were given by Prof. Langley in a paper read before the American Association for the Advancement of Science, in 1876. Since then, bars rolled from these ingots have been experimented upon, and the specific gravities of the bars and of various hardened pieces and of re-softened pieces have been determined.

These experiments will now be described.

Table I gives the analyses and specific gravities of the ingots.

Table II gives the specific gravities of six of the bars, and the specific gravities of the same bars heated to various temperatures and hardened.

Table III gives the specific gravities of the six bars, and the six hottest pieces numbered 1 in Table II, after having been annealed from the condition given in Table II.

Table IV gives the specific gravities of four pieces, all from the same bar, after various treatment.

Table V gives the results of repeated hardening of three pieces of steel containing different quantities of carbon.

Consideration of the tables :

Table I contains the analysis of twelve ingots, numbered in the left-hand column from 1 to 12.

## Table I

| Ingot Numbers | C. | Si. | Ph. | S. | Fe. by Difference | Sp. Gr. Ingots |
|---|---|---|---|---|---|---|
| 1 | .302 | .019 | .047 | .018 | 99.614 | 7.855 |
| 2 | .490 | .034 | .005 | .016 | 99.455 | 7.836 |
| 3 | .529 | .043 | .047 | .018 | 99.363 | 7.841 |
| 4 | .649 | .039 | .030 | .012 | 99.270 | 7.829 |
| 5 | .801 | .029 | .035 | .016 | 99.119 | 7.838 |
| 6 | .841 | .039 | .024 | .010 | 99.086 | 7.824 |
| 7 | .867 | .057 | .014 | .018 | 99.044 | 7.819 |
| 8 | .871 | .053 | .024 | .012 | 99.040 | 7.818 |
| 9 | .955 | .059 | .070 | .016 | 98.900 | 7.813 |
| 10 | 1.005 | .088 | .034 | .012 | 98.861 | 7.807 |
| 11 | 1.058 | .120 | .064 | .006 | 98.752 | 7.803 |
| 12 | 1.079 | .039 | .044 | .044 | 98.834 | 7.805 |

The ingots were selected by the eye and numbered as in the table by Mr. Charles Parkin, with a view to varying quantities of carbon only.

It will be seen that the carbon increases with the numbers regularly, but not uniformly.

Although a repetition of the analyses of Nos. 7 and 8 confirm Prof. Langley in the correctness of his figures, it must be admitted that in this case Mr. Parkin was quite as

lucky as skillful, for it is hard to believe in a really observable variation of structure due to a difference of only 0.004 carbon.

In the columns for Si., Ph. and S. the entire absence of progressive quantities shows clearly that these elements had nothing to do in determining the characteristic fractures.

The column of iron by difference happens to run with the carbon column, except in No. 11, where the series is broken by the abnormal amount of Si. in that ingot. Theoretically, of course, the specific gravities should run with the iron by difference, but they do not do so in ingots 3 and 5. These, however, are the only exceptions; this may have been caused by incomplete or unusually hot melting, or by hot or cold pouring, or by slow or fast pouring.

These exceptions do not vitiate the rule, and only show that no one set of experiments can be conclusive.

## Table II

| | Sp. Gr. Pig | Sp. Gr. Bar No. 6 | Difference | Sp. Gr. Bar No. 5 | From Bar, Difference | Sp. Gr. Bar No. 4 | Difference from Bar | Sp. Gr. Bar No. 3 | Difference from Bar | Sp. Gr. Bar No. 2 | | Sp. Gr. Bar No. 1 | Difference from Bar |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 3 | 7.841 | 7.844 | .003 | 7.831 | .013 | 7.826 | .018 | 7.823 | .021 | 7.814 | .030 | 7.818 | .026 |
| 4 | 7.829 | 7.824 | .005 | 7.806 | .018 | 7.849 | .025 | 7.840 | .006 | 7.811 | .013 | 7.791 | .033 |
| 6 | 7.824 | 7.829 | .005 | 7.812 | .017 | 7.808 | .021 | 7.780 | .049 | 7.784 | .035 | 7.789 | .040 |
| 8 | 7.818 | 7.825 | .007 | 7.790 | .035 | 7.773 | .042 | 7.758 | .067 | 7.755 | .070 | 7.752 | .073 |
| 10 | 7.807 | 7.826 | .019 | 7.812 | .014 | 7.789 | .037 | 7.755 | .071 | 7.749 | .077 | 7.744 | .082 |
| 12 | 7.805 | 7.825 | .020 | 7.811 | .014 | 7.798 | .027 | 7.769 | .056 | 7.741 | .084 | 7.690 | .135 |
| | | 6 | | 5 | | 4 | | 3 | | 2 | | 1 | |
| | | Not heated | | Low red heat | | Red hot | | High red | | Yellow hot | | Nearly white Scintillating | |

The twelve ingots under consideration were hammered to 1¼-inch square bars at one end, and these bars were rolled to .625 diameter round bars.

Six of these bars, Nos. 3, 4, 6, 8, 10, 12, were selected for specific gravity tests; bar No. 2 was lost, or it would have been used instead of No. 3.

Six nicks were made around each bar at one end at intervals of about half an inch.

The six pieces were numbered from 1 at the end to 6.

Each notched bar was then heated until piece No. 1 was scintillating or nearly white hot; No. 2 was yellow hot; No. 3, high red hot; No. 4, red hot; No. 5, barely showing any red, or very low red hot; No. 6, black.

This heating was done in each case as slowly and as carefully as possible. The results show the inevitable irregularities attending only one such experiment, yet there is enough of regularity to teach us a great deal.

As soon as the heats were obtained the bars were quenched in water.

The pieces, carefully numbered, both with the ingot numbers and with the numbers giving their order on the bars, were then broken off and sent to Prof. Langley to have the specific gravities determined. In the table the left-hand column gives the ingot numbers.

The other columns give the specific gravities of the ingots, the bars, No. 6 pieces, and of the other five hardened pieces in order, as numbered in the sketch and explained before.

The differences are, first, the difference between the Sp. Gr. of the ingots and the bars; second, the difference between the Sp. Gr. of the bar, or piece No. 6, and each piece successively.

The differences of Sp. Gr. are given in preference to the actual differences in volume, because the differences in volume run into the infinitesimals, and the mode adopted answers as well for purposes of comparison.

On comparing the ingot and bar we see a decided increase in the Sp. Gr. of the bar in every case except one, that of No. 4. We have not discovered the reason of this anomaly. The increase in the other cases is due to hot working; this will be shown by Table IV.

It will be observed that the Sp. Gr. of the bars, except in No. 3, is nearly uniform.

This seemed very strange at first, but it is capable of a very simple explanation. The hardness of steel and its resistance to change of form increase very rapidly with an increase of carbon, and as these bars were all reduced from 3-inch square ingots to 5/8-inch round bars, it is obvious that it required much more work to reduce No. 12 than No. 4 or No. 6; therefore, as hot working increases Sp. Gr., the greater amount of work produced the greater increase in the Sp. Gr. of No. 12.

If the Sp. Gr. of the right-hand column pieces No. 1 be compared to the Sp. Gr. of the ingots, it will be seen that the relation between the numbers is entirely restored by the high heat to which the No. 1 pieces were subjected.

If the Sp. Gr. of pieces Nos. 5, 4, 3 be examined carefully, sufficient irregularities in the difference columns will be observed to show that the heating was not accomplished in regular gradations in each case, and if it were desired to lay down an exact law of variation due to differences of temperature, it would be necessary to take the mean of a great many experiments.

Nevertheless, several general laws are indicated in this table.

1. The Sp. Gr. of the ingot varies directly with the quantity of iron present.

2. The greater the quantity of carbon present, the greater is the amount of work necessary to produce change of form.

3. The greater the quantity of carbon present, the greater is the change in volume due to a change of temperature.

As, for example, in No. 3 the change in Sp. Gr. from the ingot to the bar in only .003, and from the same bar to the piece No. 1 the change is .026.

While in No. 12 the change in Sp. Gr. from the ingot to the bar is .020, or about seven times that in No. 3, and the change from the bar to the piece No. 1 is .135, or about five times the change in No. 3.

This is perhaps the most important observation that can be made on this series of experiments, as it shows us why it is that high steel is so much more liable to crack and break in manipulation than low steel.

We generally say one is brittle and the other is ductile; we now know that the rate of expansion per degree of temperature is much less in low steel than in high steel. Therefore, low steel is much less liable to injurious internal strains than high steel.

In order to settle the question of restoring "burned steel," so called, and also to determine the reverse action due to annealing, Prof. Langley took the six pieces No. 1 of Table II, and heated them all to a high yellow heat. He then allowed them to cool very slowly.

This raised a heavy scale on the pieces, which was removed by touching them on an emery wheel.

The specific gravities of these pieces were then taken, and the results are given in the table.

The restoration to the Sp. Gr. of the bar is complete, as the differences are only such as might be due to the scale

## Table III

| Ingot Numbers | Sp. Gr. of Bars No. 5 | Sp. Gr. of Burned Pieces Annealed, No. 1 | Differences |
|---|---|---|---|
| 3 | 7.844 | 7.857 | + .013 |
| 4 | 7.824 | 7.846 | + .022 |
| 6 | 7.829 | 7.835 | + .006 |
| 8 | 7.825 | 7.828 | + .003 |
| 10 | 7.826 | 7.824 | .002 |
| 12 | 7.825 | 7.822 | .003 |

on the original bars and the removal of the scale from the annealed pieces. This will be shown further in Table IV.

It is well known that cold rolling does not increase the Sp. Gr. of iron or of steel. To ascertain the effect of cold hammering under the best conditions to increase Sp. Gr., namely, by hammering between semi-circular dies, an experiment was made, the results of which are recorded in Table IV.

A round bar, of carbon about 1 per cent., was operated upon.

The bar, as it came from the rolls, and unannealed, was 0.682 inch in diameter: this is No. 1 in the table.

A piece of the same bar, annealed and pickled, was 0.673 inch in diameter: this is No. 2 in the table.

The same bar twice hammered cold, after annealing, was reduced to 0.624 inch in diameter; this is No. 3 in the table.

The same bar annealed, and hammered cold four times, was reduced to 0.564 inch in diameter; this is No. 4 in the table.

## Table IV

### Drill Rod Samples

| Nos. | 1 Sp. Gr. | 2 Sp. Gr. | 3 Sp. Gr. Scaled and not Hardened | Diff. 3-2 Effect of Hardening | Diff. 3-1 Effect of Scale off in 1 and 2 |
|---|---|---|---|---|---|
| 1 | 7.8068 | 7.818 | 7.829 | −.011 | +.022 |
| 2 | 7.794 | 7.812 | 7.828 | −.016 | +.034 |
| 3 | 7.816 | 7.790 | 7.817 | .027 | +.001 |
| 4 | 7.787 | 7.765 | 7.780 | −.015 | .007 |

Prof. Langley first took the Sp. Gr. of the four pieces as he received them, 1 and 2 having the roll scale upon them, and 3 and 4 being bright polished, all having been boiled in dilute potash and slowly cooled. The results are given in column No. 1.

In this case No. 3 indicates an increase of Sp. Gr. due to the cold hammering. Prof. Langley then, thinking that the results might have been affected by scale in the first two pieces, next removed the scale and boiled them all in weak potash, and upon removing them from the boiling liquid cooled them rapidly by plunging them quickly into cold water.

Column No. 2 gives the results, and here we have the remarkable fact that sudden cooling from boiling temperature

causes a hardening effect, which is shown more particularly in Nos. 3 and 4, where there is a decided reduction of Sp. Gr.

If subsequent trials prove this deduction to be correct, it is very important. Desiring to fortify himself as to this matter of hardening at such a temperature, Prof. Langley again boiled the pieces and allowed them to cool very slowly, thus annealing them. The results are given in column No. 3.

Here is a progressive reduction of Sp. Gr., showing that cold hammering as well as cold rolling reduces Sp. Gr. The restoration of the Sp. Gr. of 3 and 4 to the results in column No. 1 shows that there was a hardening due to quenching from boiling temperature. The column of differences 3 and 2 shows the effect of hardening. The column of differences 3 and 1 shows the effect of removing the scale. This column also accounts for the increase of Sp. Gr. shown in the "restored" or annealed pieces of No. 1, Table I, recorded in Table III. The results recorded in Table IV have an important bearing on the inquiry into the cause of hardening, which will be shown later. They are also important as showing the entirely mercurial or thermometric nature of steel. They also indicate a mode of accurate determination of the variable rate of change of volume in steels of different composition.

It will be remembered that there is such a variable rate of change clearly shown in Table I, and further evidence will be given in Table V.

Now, by operating upon different samples by boiling, and sudden cooling in water of uniform temperature, we can get results which will range between certain uniform and known temperatures for each experiment.

This is an experiment to find by measurement the effect of repeated hardening upon three pieces of steel containing different amounts of carbon.

A hole about .75 inch in diameter was drilled in the middle of each piece. The measurements were taken by means of a tapered plug, the difference in the distance to which it entered in each case, after the first and subsequent hardening, being measured by micrometer. The left-hand columns give the numbers of the successive hardenings. The other columns show the changes in the diameter of the hole. The first piece, of carbon .848, showed contraction of the hole every time it was hardened except the sixth,

## Table V

### Changes in Volume by Repeated Hardening

| No. of Times Hardened | Nos. 6 and 7, Table I C = about .848 | No. 4, Table I C = .649 | | No. 3, Table I C = [illegible] | |
|---|---|---|---|---|---|
| | Contraction of Hole | Expansion | Contraction | Expansion | Contraction |
| 1 | .00172 | . . . . | .00257 | . . . . | .00086 |
| 2 | .00172 | . . . . | .00086 | . . . . | .00172 |
| 3 | .00688 | . . . . | .00482 | . . . | .00000 |
| 4 | .00688 | . . . . | . . . . | .00172 | . . . . |
| 5 | .00688 | .00172 | . . . . | .00086 | . . . . |
| 6 | .00000 | . . . . | .00172 | .00086 | . . . . |
| 7 | .30044 crack'd | not cracked | .00000 | not cracked | .00086 |
| Total change | .02752 | . . . . | .00771 | .00000 | .00000 |

Hole was originally .75 diameter

and the piece cracked at the seventh hardening. The operator supposes the sixth hardening was accidentally omitted.

The second piece, of carbon .649, showed contraction three times, then no change. Then an expansion of the hole followed by a contraction, and the seventh time there was no change. This piece did not crack.

The third piece, of carbon .529, showed two contractions, then no change, followed by three expansions, and seventh a contraction. This piece did not crack.

The total changes are quite marked:

| | | |
|---|---|---|
| Showing for carbon . . . . . . . . | .848 = | .02752 inch |
| Showing for carbon . . . . . . . . | .649 = | .00771 inch |
| Showing for carbon . . . . . . . . | .529 = | .00000 inch |

This shows in another way that steel of high carbon changes more in volume per degree of temperature than steel of low carbon.

The high steel cracked, the low did not. All the pieces were of the same quality.

The experiment recorded in Table No. V forms no part of the investigation by Prof. Langley and ourselves. It was made rather crudely for a practical purpose, and the results obtained in practice confirm the figures in the table.

This ends our record of facts and brings us to—

4. A statement of some of the theories which have been given as the cause of hardening.

Perhaps the oldest, one of the most plausible, and possibly the true reason, is that unhardened steel contains carbon in

graphitic and uncombined form, and hardened steel has its carbon all combined.

For proof it is stated that when unhardened steel is dissolved, the insoluble residue contains flocculent graphitic carbon; and when hardened steel is dissolved it leaves no residue of carbon; therefore, the carbon has been combined in the hardening. To answer the objection to this, that it is impossible for iron and carbon to combine in all proportions, one writer states that there is formed a definite carbide $FeC_4$.

That this carbide is excessively hard, and that it acts as a cement or glue, and therefore the high carbon steel becomes so much harder than the low carbon steel.

This will be conclusive after the carbide has been separated and thoroughly examined. Meantime, the hardening from boiling temperature is a little puzzling.

Another writer states that solution of the carbon takes place when the steel is heated, and that a great compression caused by the sudden contraction in cooling is the cause of hardness.

If this be so, and our experiments are correct, then carbon dissolves in steel at the temperature of boiling water.

One writer hastens to inform us that steel hardens because part of the carbon is burnt out in heating, and the rest of the mass is compressed by the sudden cooling. It might afford amusement to demolish this theory, if it would not be a waste of time.

A steel maker of twenty years' practice says hardening is caused by the carbon assuming the diamond form, in very minute crystals.

He gives as a proof, that the hot steel decomposes water, or the cooling mixture, which always contains hydrogen.

The hydrogen combines with the carbon to form diamonds, and this is proved by the fact that the diamond and hardened steel both refract light.

In case water is the cooling medium, the hydrogen penetrates the steel to form diamonds, while the freed oxygen, conveniently inert, stays on the outside to form a thin film of oxide.

As it is well known that mercury is one of the very best cooling liquids, giving extreme hardness to steel, it is necessary to this theory to show that mercury contains hydrogen.

Again, if steel really hardens upon being quenched from boiling temperature, then water must be decomposed by that temperature.

This diamond theory is very attractive, and has received much consideration in our minds, but we are not prepared to consider it proven.

Another writer states that hardening is due to the sudden arresting of the molecular motion that exists in the heated steel, thus causing great tension and resulting hardness. He offers, as proof, that hardened steel is weaker and more brittle than unhardened steel, and cites as a very happy illustration the case of hardened glass which is known to be in a high state of tension. This theory tallies with all the facts better than any we have seen.

First, it covers all conditions, from the boiling temperature up to the high yellow heat which causes intense hardness and the brittleness of glass.

Again, it is certain that the higher the heat the greater the molecular motion. Also it is certain that from the highest heat we get the greatest hardness, and the greatest brittleness.

Finally, the restoration of grain, and of Sp. Gr. by annealing, agree well with the idea of tension in one case, and the relief from tension in the other.

It is possible, even if this tension theory be accepted as correct, that there may be, in connection with it, a change to diamond form, or from graphitic to combined carbon, and the formation of a definite carbide. Some one of these changes, taking place at a given temperature, may be just what is needed to explain that very remarkable phenomenon known as "refining."

In mentioning a few practical considerations to be drawn from what has been said, it is hardly necessary to address the unfortunate smith and temperer; they, poor fellows, have heard so much of uniform heating and low heating, that they may well feel heart-sick, and determined to do as they please anyhow.

Let them do as they will, they will never be allowed to forget that same old cry — "too much heat" — "irregular heat" — and so on.

Let that cry continue; it has its uses; and let us look at the engineer's side.

As steel advances with irresistible steps into the field of construction, the engineer naturally asks — What am I to do with it?

Can it be worked safely?

Is it reliable?

Shall I use high steel or low?

How is it to be worked?

Is it safe to use the apparent advantages of great strength to be had in high steel?

Is it necessary to anneal finished work? etc., etc.

We think it has been clearly shown—

1. That a good soft heat is safe to use if steel be immediately and thoroughly worked.

It is a fact that good steel will endure more pounding than any iron.

2. If steel be left long in the fire it will lose its steely nature and grain, and partake of the nature of cast-iron.

Steel should never be kept hot any longer than is necessary to the work to be done.

3. Steel is entirely mercurial under the action of heat, and a careful study of the tables will show that there must of necessity be an injurious internal strain created whenever two or more parts of the same piece are subjected to different temperatures.

4. It follows that when steel has been subjected to heat not absolutely uniform over the whole mass, careful annealing should be resorted to.

5. As the change of volume due to a degree of heat increases directly and rapidly with the quantity of carbon present, therefore high steel is more liable to dangerous internal strains than low steel, and great care should be exercised in the use of high steel.

6. Hot steel should always be put in a perfectly dry place of even temperature while cooling. A wet place in the floor might be sufficient to cause serious injury.

7. Never let any one fool you with the statement that his steel possesses a peculiar property which enables it to be "restored" after being "burned;" no more should you waste any money on nostrums for restoring burned steel.

We have shown how to restore "overheated" steel.

For "burned" steel, which is oxydized steel, there is only one way of restoration, and that is through the knobbling fire or the blast furnace.

"Overheating" and "restoring" should only be tried for purposes of experiment. The process is one of disintegration, and is always injurious.

8. Be careful not to overdo the annealing process; if carried too far it does great harm; and it is one of the commonest modes of destruction which the steel maker meets in his daily troubles.

It is hard to induce the average worker in steel to believe that very little annealing is necessary, and that a very little is really more efficacious than a great deal.

Finally, it is obvious that as steel is governed by certain and invariable laws in all of the changes mentioned, which laws are not yet as clearly defined as they should be, nor as they will be; nevertheless, the fact that there are such laws should give us confidence in the use of the material, because we may be sure of reaching reliable results by the proper observance of the laws, therefore there is no good reason why engineers should be afraid to use steel if they manipulate it intelligently.

Now, if we have wandered over a wide range in answer to the simple question—"Why does steel harden?" it was necessary to have looked at many facts before we could have an intelligent opinion of many theories; and if any are in doubt as to what is the correct answer to this momentous question, we can only say that we are all in the same boat, for if you do not know, neither do we.

# Hardening and Tempering Steel

From a work by George Ede,
Woolwich Arsenal, England

We have now arrived at a very important process, justly termed the crowning process. It is that of hardening the articles; and, if the proper steel has not been chosen for the articles, or if the proper steel has been chosen and has not afterward been properly treated through all the stages which it has had to pass, or if the hardener be not fully aware of the general principles upon which he must proceed, all past efforts may prove futile. It is not requisite that the hardener should be a chemist; but some slight acquaintance at least with chemistry, or of the action of substances upon each other, will be extremely serviceable to him. To be unqualified in this respect will be laboring in the dark: a successful result may often be obtained; but it will be very imperfectly known how it happened, and it will afford no valuable instruction for the future.

There are *too many who entertain an opinion that they have nothing new to learn which is worth notice*; they are apt, in effect, to say, that, having served an apprenticeship to their business, they ought to know something, and because they ought to know something, they seem to expect submission to their very errors. To such I speak not; to convince them would be impossible, and therefore the attempt folly. But the prudent artisan, whose first care is generally to provide himself with tools adapted to his labors, I would ask to improve his knowledge of that material, the pröper choice

and management of which constitutes the first step toward success in mechanical pursuits.

The art of hardening and tempering steel constitutes one of the most delicate, curious, and useful branches connected with mechanical art; it is an art of long standing, and always one of anxiety, but by whom or when it was first adopted I am not prepared to decide. At first sight it appears sufficiently simple, when by heating a piece of steel to redness, and plunging it into cold water, it becomes hard; on a closer inspection, however, the mind will soon discover that many operations and contrivances require to be carried into effect by the hardener in order to become efficient in his art, or to be distinguished for skill and promptitude in execution. A slight knowledge of the processes will also discover that a certain amount of patient perseverance is required—an amount of which few who have been brought up at the desk, or behind the counter, can form the slightest idea. But I have not set out with the object to discourage the young practitioner, but rather to encourage him and smooth for him the path which I have myself found so rough, but which I have always endeavored to explore without entertaining a sentiment of its hardship; and I would advise all young men who are just starting in the world to go and do likewise.

Before proceeding further, I would state, that I have not undertaken to explain everything in connection with this subject; but my main object in the present chapter is to explain, in a plain way, the chief causes why steel breaks in hardening; also to notice some of the contrivances which I have found in my own experience to be the least expensive, and most easily reducible to practice; the most suitable to prevent steel from breaking; and, if the information be

properly studied, it will enable the mechanic to harden and temper any kind of article with which he may have to do.

Many theories upon the cause of steel becoming hard by the process of heating and suddenly cooling it have been formed; but they are so beset with difficulties and uncertainty, that in my opinion the proper cause has not yet been proved. I have previously shown that steel is a compound of iron and carbon; and, as pure iron does not harden by simple immersion, it must be to its carbon that steel owes this valuable property; and, if I may be allowed to theorize on the reason why steel becomes hard by sudden cooling, I should be inclined to state that it is the crystallization of the carbon, caused by compression and sudden cooling, and, being combined with the iron, becomes a hard and solid substance; but, let this be so or not, there is one thing certain, that a new arrangement of the particles takes place by the process of hardening. But, as I shall have an occasion to speak upon this hereafter (in the chapter upon the expansion and contraction of steel), it will be superfluous to speak upon it in this place, but rather confine myself to the mechanical operations of the subject.

It is of considerable importance that the designer of tools or other articles should have some knowledge of the quality of the material to be used; likewise he should have some knowledge of the action of fire and water upon the material; also he should have some knowledge of the practice of the hardener.

The workmen, through whose hands the articles must pass, either in the fitting or the turning room, should also have some knowledge of the art of hardening; in fact, it is as requisite that fitters and turners should have some knowl-

edge of the practice of the hardener and the action of fire and water upon the steel, as it is for the pattern maker to have some knowledge of the practice of the molder.

The superior character of castings depends in a great measure upon the superior skill which has been displayed upon the patterns; and the success in the hardening of steel, in many instances, depends in a great measure upon the ingenuity displayed in the fitting or the turning room, and also on the ingenuity displayed in designing the article.

Too little attention is generally paid to the quality of the material when required for very particular tools, or, in other words, for tools that require a great amount of labor and time to make them; and in the fitting or the turning room, or even in the drawing office, the expansion and contraction of steel is seldom heeded or even thought of, though it is of the greatest importance.

When it is required to make an expensive article, and where there is great risk of its breaking in the hardening, the first thing to be done is to select the proper steel for the purpose and afterward to anneal it to the fullest extent; if an equal and judicious hammering be given to the steel by the smith before it is annealed, it gives a density to the steel, and the article will be more durable; besides, it will lessen the risk of its breaking in the hardening, but the effect of the hammering, as I have before remarked, is taken off again by strong ignition, and the smith's labor is lost; therefore it is evident that there is as much care required in heating the steel when it is required to be annealed as there is in heating it when it is required to be forged or hardened. When the steel is annealed it is then in a fit state for the

fitting or the turning room, there to be fashioned into the required article.

The artist employed upon it ought to bear in mind that steel breaks in hardening from its unequal contraction at different parts; the danger increases with the thickness and bulk, and the more especially when certain parts are unequally thick and thin, consequently before finishing any article for hardening one thing should be attended to, which I will attempt to explain, and, if I succeed in making it understood, the artist will have obtained information as to the plans to be adopted with large articles generally. It is this: examine the article and see which part of it is likely to be the last to become cold when it is immersed in the water, and if it is practicable to reduce the steel in that part without inconveniencing the article it is advisable to do so; the steel will then cool more uniformly and be less liable to fracture. If it were possible to get every particle of the steel cold at the same moment, there would be an end to the danger of steel breaking in hardening; but as this cannot be done, we must approach it as near as we can.

For the better understanding of the subject, let us suppose that a large circular cutter, such as are used for shaping and truing of work of various shapes, is required to be made. We will suppose it to be required about 7 inches in diameter and 2 inches in thickness, with numerous cutting edges (termed teeth) round the circumference, and a round hole in the center through which to pass the spindle. It is obvious that the first thing which will require to be done will be to select the proper steel for the cutter and afterward to forge it to the required dimensions, after which it will require to be annealed to the fullest extent; but as

the choosing, forging, and annealing have already been treated of, it will be superfluous to speak more upon it in this place, consequently, let us suppose the steel in its forged and annealed state to be obtained. The first thing usually done after the steel is obtained is to bore the mandrel hole, after which it is turned to the required thickness, and the two sides of the block of steel left flat; the superfluous metal upon the circumference is then turned off, which leaves the block of the required diameter. The teeth are now cut upon the circumference of this block of steel, either by means of a file or by a tool whose edge is of the proper form, and can be used either in a planing or shaping machine, or even with the lathe. But the most perfect teeth are cut by means of another rotary cutter, whose edge is of the proper form, and working in a machine constructed for the purpose. It is usual to bore the mandrel hole in large cutters the same size as the mandrel hole in the smaller size cutters, so that both large and middle-size cutters may fit the same mandrel, but this is a step in a wrong direction. The larger the cutter the larger the mandrel hole should be —not to say that the mandrel itself would not be strong enough; but a large mandrel hole in large cutters favors the cutters in hardening by allowing the steel to cool more uniformly; whereas a small mandrel hole in a large cutter, having two plain flat sides or surfaces, increases the risk of the cutter breaking in hardening. Though a large mandrel hole favors a large cutter in hardening, still it is not absolutely necessary to have a large mandrel hole in them, because large cutters having a small mandrel hole in them may be hardened without breaking them, by taking care previous to hardening them to reduce the substance of the steel.

The substance of the steel must be reduced in that part of the cutter which is the last to become cool when it is immersed in the water. It is obvious that the part which is the last to become cold will be half way between the mandrel hole and the circumference, consequently large cutters will require to be dished out or turned concave on both sides; or if a few smaller holes than the mandrel hole be bored round the mandrel hole, it will answer the same purpose as turning each side concave. Either of the above plans will greatly reduce the risk of all large cutters breaking in hardening, and it does not materially reduce their strength or stability.

It is obvious that the method of turning the sides of large cutters concave cannot be adopted with cutters which require to have teeth on their sides as well as on their circumference; still holes could be bored through these, and probably it would not in the least prevent the cutter from doing its work; still the cutter would not have a very pleasing appearance, and it would not look very mechanical. Consequently, instead of boring holes in these kinds of large cutters, it will be better to make the mandrel hole large in proportion to the cutter.

Perhaps it will be of some use to hint, as it is a very valuable hint if properly taken, that a circular cutter of any required thickness, and 7 inches in diameter, and which has a 3-inch mandrel hole through its center, is less liable to break in hardening than a circular cutter of the same thickness, 6 inches in diameter, and which has a 2-inch mandrel hole through its center.

There are numbers of articles besides cutters which require to be hardened, where it becomes necessary to bore holes in them, or cut out a kind of panel to make them cool

more equally. In some instances boring holes in steel a
cles requiring to be hardened is injurious or unfavorable
the articles in hardening. For instance, boring holes
near the outside edges of some kinds of articles will so
times cause the article to crack at the hole.

It may be well to state that drilling a hole or center
large or too deep into screw taps or reamers, and various ot
articles which require to be hardened, is a great evil
should in general be avoided; for, when the centers
too large or too deep, it weakens the ends of the artic
and it not only weakens the ends of the articles, but it
quently causes a fracture in the steel at the bottom of
center.

In all cases, if the centers are not required in the artic
after they are hardened, it is advisable to file them out p
vious to hardening them, and thus prevent all risk of th
getting cracked at that part in hardening.

In making steel tools or steel articles of any descript
sharp internal angles should in general be avoided, as th
are very unfavorable in the hardening process; consequen
the key ways in cutters should be half circle. In all ki
of articles sharp internal angles are unfavorable to
strength of the articles, so that it becomes necessary to le
all the internal corners a little rounded.

It may be useful, perhaps, to add that cutters which
required for cutting soft substances, such as brass or copp

polish and glide over the metal almost without effect, were the cutters not seconded by a great amount of power.

When a steel tool or piece of work similar in shape to a piece of a bar of round steel, say, 2, 3, 4, or more inches in diameter, and 3, 4, 5, or more inches in length, is required to be hardened, it frequently becomes necessary, previous to hardening such a tool or piece of work, to bore a hole through the center of it, in the direction of its length, in order that the water may pass through the hole, and cool the steel more equally, and reduce the risk of its breaking. But as the two ends are even then always likely to become cool first, it would not be amiss to widen the hole a little more in the center than at the ends, and so further reduce the risk of its breaking in hardening.

It is unnecessary, perhaps, to remark, that the largest size screw taps and hobs are very liable to break in hardening, and, though a hole might be bored through them to prevent their breaking, still this would not give a very pleasing appearance, nor would it look very mechanical. Independent of the appearance of the tap or hob, a hole through large screw taps or hobs would be very apt to cause them to become oval in hardening; and if this did occur it would cause the tap, when in use, to make the hole larger than it was intended to do, and cause the hob when in use to cut very unequally and very slowly, because only two opposite sides of the hob could be made to cut.

It is obvious that a round piece of steel having a plain or smooth surface, and which has a hole bored through it in the direction of its length, would be as likely to become oval in hardening as a piece of steel having a similar hole through it and a screw upon its surface, such as a tap or hob.

But then there are means by which a plain surface can be made true again after hardening, such as by lapping or grinding, whereas with taps or hobs these methods cannot be adopted. In all cases it must be borne in mind that, the more uniformly articles are heated, the less liable are they to become crooked or oval in hardening.

For the various reasons above given, another method differing from the boring of holes through large taps or hobs may be adopted, a method which will not at all disfigure the taps or hobs, or cause them to become oval, but which will cause them to harden and cool more uniformly, at the same time prevent them breaking. It is this: to turn the plain part of the tap or hob as small as it will conveniently bear without encroaching upon the required strength of the tap or hob, and to cut the concave grooves (which are in the direction of the lengths of the best kind of taps) a little deeper than what they are generally cut.

The method of reducing the steel in that part of large articles which is the last to become cold when they are immersed in the water, cannot with some kinds of articles be adopted; because, were the steel to be reduced in that particular part, it would unfit the articles for the purpose for which they are intended. This would be the case with large circular dies, which frequently require to be turned flat on both sides. It is obvious that the method of boring holes through these kinds of articles, or turning the sides of them concave, cannot be adopted; consequently another method must be resorted to. It is this: to heat an iron ring or collar, and while the die is in a cold state shrink the heated ring tight upon the die; this method will, when the die is heated and immersed in the water, lessen the risk of fracture.

It will be imagined, perhaps, that the object of shrinking a ring upon the die is to compress the die, and by compressing the die it will keep it from breaking; now, if this were the object, it would be a step in the wrong direction. The object of shrinking a ring upon the die is to prevent the water from cooling the outside of the die too suddenly. It must be borne in mind that the more suddenly the heat is extracted from the steel, the more sudden is the contraction of the surface steel; and the more sudden the contraction of the surface steel, the more sudden and greater is the compression of the interior steel; and the more sudden and greater the compression of the interior steel, the greater is the risk of the steel breaking by the outer crust being held for the moment in a greater state of tension (strain). The more the interior steel is compressed the more dense it becomes; consequently, when it becomes cold it occupies less space than what it occupied previous to hardening, and the result is an internal fracture.

It will not be out of place, perhaps, to remark that if every mechanic were made more acquainted with the chemical properties of the material, and the action of fire and water upon the material, thousands of articles which have been thrown aside might have been prevented from being burnt in forging, and thousands more would have been saved from being cracked in hardening; and the price paid upon the forging, annealing, turning, fitting and hardening, or making articles from bad material, might have been saved.

Suppose a similar block of steel to the one just treated of to be required for a large friction wheel, the method of shrinking a ring upon it previous to hardening of it will not answer, because the ring would prevent the water from effec-

tually hardening the steel in that part which is required the hardest; consequently the same methods will have to be adopted with this kind of article as those which are to be adopted with a large circular cutter, either boring holes through it or turning the sides concave. Suppose an eccentric steel collar is required to be hardened, for example. Let us suppose the hole in the collar where the shaft or mandrel passes through to be about two inches in diameter, and the thickness of the metal one inch and a half on one side and about the quarter of an inch on the opposite side; from the irregular form of this article it will easily be seen that there is great risk of its breaking in hardening. The unequal thickness of the steel causes unequal contraction, one side of the collar being so thin it is cool almost instantly. The stout side contracts after the thin side is fixed; the thin side in its then hard state cannot give; consequently it breaks. Before such an article as this is sent to the hardener, a piece of iron should be fitted to the thin side of it, so as to make both sides about equal in thickness. The iron must be fitted to the inside, as it is the outside of the collar which is required hard. This piece of iron is to prevent the thin part of the collar from cooling too suddenly, and thus prevent the collar breaking. The piece of iron, of course, must be bound upon the collar with a piece of binding wire, after which it is ready for hardening. I may here remark that a square lump of steel is less liable to break in hardening than either a cylindrical or spherical lump, even though there be more bulk in the square lump than what would form either the spherical or the cylindrical lump.

Although this is such an important subject, and much more might be said, still it is not necessary, perhaps, to en-

large more upon it, as the mind will have discovered by this time the method of proceeding with tools or articles of any description requiring a great amount of labor and time to make them; and where there is great danger of their breaking in hardening. The same or similar methods will have to be adopted in all cases where large masses of steel require to be hardened, if we wish to obtain satisfactory results.

The information here afforded, coupled with the workman's own experience and ingenuity, will doubtless be sufficient to prevent his finding difficulty in forming for himself any particular idea upon the subject he may want; consequently I will now pass on to the process of hardening and tempering.

In the process of hardening steel, water is by no means essential, as the sole object is to extract its heat rapidly, and the more sudden the heat is extracted, the harder the steel will be; consequently, those substances which act most suddenly upon the steel will produce the greatest effect, though they will not always produce the most satisfactory results, for intense cold has a very unfavorable effect upon steel. Good cast-steel receives by sudden cooling a degree of hardness almost equal to that of the diamond, and almost sufficient to cut, or make an impression upon, every other substance; and, when of the best quality, and the hardness not carried to extreme, a certain amount of tenacity is also combined with the hardness.

If steel is heated to a red heat, and allowed to cool gradually, it becomes nearly as soft as pure iron, and may, nearly with the same facility, be worked into any required form. If steel be too hard, it will not be proper for tools, or instruments of any description, which are required to

have very keen edges, or very fine points, because it will be so brittle that the edges will soon become notched, or the points break off on the slightest application to the work; if, on the contrary, the steel be too soft, the edges or points will turn or bend; but, if the steel is duly tempered, it will resist breaking on the one hand and bending on the other.

The degree of heat required to harden steel is different in the different kinds. The best kinds require only a low red heat; the lowest heat necessary to effect the desired purpose is the most advantageous, and to impart to it any extra portion of heat must partly destroy its most valuable properties; and for this misfortune there is no remedy, for, if cast-steel is overheated, it becomes brittle, and can never be restored to its original quality; therefore, it will be quite incapable of sustaining a cutting edge, but will chip or crumble away when applied to the work.

There are various ways of applying the heat to articles when they require to be hardened. The methods to be adopted will of course depend upon the shape and size of the articles; also upon the quantity requiring to be operated upon, for in some instances a large quantity can be heated and hardened as expeditiously as a single article. Sometimes it is requisite to heat the articles in the midst of the fuel in a hollow fire; sometimes it is requisite to heat them in an open fire; and sometimes it is requisite to inclose and surround them with carbon in a sheet-iron case or box, and heat the whole in a hollow fire or in a suitable furnace; at other times, or in some instances, it is more convenient to heat them in red-hot lead When a large quantity of some kinds of articles is required to be hardened, the method of heating them in red-hot lead is very convenient and very

economical; but to be constantly employed dipping articles in red-hot lead is, I believe, very injurious to health. I have myself been so employed, and have felt its very bad effects; and I have, therefore, avoided using it as a source of heat except in cases of great necessity.

A more uniform degree of heat can be given to some articles by heating them in red-hot lead than by any other means, especially some kinds, which are of great length; consequently, they will keep their proper shape better in hardening. A gas flame, or the flame of a candle, is very convenient for heating the point of some small articles; some small articles may be sufficiently heated by placing them between the red-hot jaws of a pair of tongs. Some small articles may be heated by taking a piece of bar iron, and, after heating it to redness, cutting it half-way through with the chisel, and then placing the articles in the nick, which will heat them sufficient for hardening. Sometimes it is necessary to insert a piece of iron pipe in the midst of the ignited fuel of the fire, and then to place the articles in the pipe.

When a large number of steel articles are required to be hardened all over, or throughout their body, and which are too small to be heated in the midst of the ignited fuel of a hollow or open fire, and perhaps it is inconvenient to heat them in red-hot lead, or if it be thought hazardous to enclose them entirely in a sheet-iron box, from an apprehension that the heat might increase too much, the following scheme may be adopted. Place as many of the articles at once as may be convenient to manage into a sheet-iron pan, without a lid, and cover them with charcoal dust; place the whole in a furnace or hollow fire, and slowly heat them to redness.

They should be occasionally and carefully moved about in the pan by the use of a small wood or iron rod, in order to equalize the heat; the charcoal dust prevents the articles from scaling so readily, and has a tendency to prevent the rod bending them when moving them about in the pan. When the articles arrive at the proper heat they may be immersed in water or oil, or water with a film of oil upon the surface, according to the degree of hardness required in them.

A rod of good steel in its hardest state is broken almost as easily as a rod of glass of the same dimensions, and this brittleness can only be diminished by diminishing its hardness; and in this management consists the art of tempering. The surface of the hardened steel is brightened, and it is exposed to heat. As the heat increases there is a curious and uniform change in the clear color of the surface. The colors which appear upon the surface of the steel are supposed to be the result of oxidation. The thickness of the coat or film of oxide, if such it be, determines the color, and the thickness of the coat depends upon the temperature to which the work is exposed.

It is quite probable that these colors are the result of oxidation; but the present state of my knowledge does not enable me to prove that these colors would not appear if the steel could be heated in a vacuum, a space unoccupied with air, neither does the present state of my knowledge enable me to prove that these colors are not due to the new arrangement of the particles, quite independent of any chemical change; but, let the cause be what it may, these colors are a very useful index, for by them any degree of hardness retained by the steel may be ascertained. The colors which

successively appear on the surface of the steel, slowly heated, are a yellowish white or light straw color, a dark straw, gold color, brown, purple, violet, and deep blue. Finally, the steel becomes red hot, and a black oxide is formed. It will be more readily imagined that the various colors are the result of oxidation, when it is seen that the action of the oxygen of the atmosphere upon the steel in a red-hot state converts the surface of the steel into a black oxide; and this black oxide, like the various colors, increases in thickness with increase of temperature, and if it is hammered or scraped off it is again quickly formed.

There are various ways of applying the heat for tempering or reducing the hardness in steel articles. The methods to be adopted will, of course, depend upon the shape and size of the articles; also upon the quantity requiring to be operated upon; for in some instances a large quantity can be tempered as expeditiously as a single article. The heat for tempering should not be too suddenly applied, as a certain amount of time is essential for the particles to rearrange themselves, and the slower the heat is applied the tougher and stronger the steel becomes. When it is required to temper an article or articles to any of the colors previously spoken of, they must be brightened after they are hardened. But before proceeding farther it will perhaps be well to state that previous to brightening the articles the hardener ought always to make himself sure that the articles are quite hard. If the articles are not properly hardened, or, in other words, if the articles are not possessed of a certain degree of hardness, it will be time and labor lost afterward to temper them; besides, the articles will be practically useless for the purpose they are intended for until they have been hardened

and tempered over again. Therefore, in order to make sure of good work, the hardener should always try the hardness of the steel with a smooth file, a file finely cut. It has already been inquired of me, and may be inquired again, perhaps, why is it necessary for a practical man who is thoroughly acquainted with the quality of the material he is hardening, likewise with the temperature suitable to harden the material, to try the hardness of the steel, when he knows from experience that the steel hardens properly at a certain temperature? The answer to this is, the hardener may be a practical man, and may be thoroughly acquainted with the quality of the material, likewise with the temperature suitable to harden the material; but if he is not a careful man his knowledge will be of little service, and the necessity for trying the hardness of the steel before it is tempered is soon made evident; besides, if proper attention is not paid to the water it will deceive the hardener. Again, the most careful and experienced hardener is liable to be deceived in the temperature of the steel when hardening in twilight. It has previously been stated that it is requisite at times to enclose some kinds of articles, when they require to be hardened, in a sheet-iron box, and surround them with charcoal. When this method is adopted, the articles will require a much more considerable amount of time to heat them than is readily imagined by those who are not accustomed to this method. Charcoal is a bad conductor of heat, and if the hardener be unacquainted with the conducting quality of the charcoal, he will be apt to draw the box out of the fire and immerse the contents in the water before the central articles have acquired the proper temperature suitable for hardening them, and those articles which are below a certain heat

cannot become hard. Here again is exhibited the necessity of trying whether all the articles are hard before beginning to temper them. In some instances (though the steel be the very best that Sheffield can furnish), one or two badly tempered articles would get the manufacturer of them a bad name, and would in some instances get all the order condemned, even if all the other articles were right. The use of the file for proving whether the articles are hard can be dispensed with when the articles are brightened on an emery wheel, or a small dry grinding stone running at a quick speed, for the person employed to brighten them will find, if they are properly hardened, plenty of brisk, lively sparks fly from them when they are held upon the emery wheel or the grinding stone. But if they are not hard there will be very little fire in them. Therefore, with a very little attention, these articles which are soft (if any there be) can be detected, and may be put aside and heated again with the next batch.

After the articles are brightened, the hardness can be reduced to any particular standard by placing them upon a hot bar or plate of iron, or upon the surface of melted lead, or in a bath of a more fusible metal kept at a certain heat, or in hot sand or burning charcoal; or the articles may be held in the inside of an iron ring heated to redness, or they may be placed in the mouth of a furnace, or in an oven heated to the proper temperature, or they may be placed in or upon a gas stove specially constructed, or they may be heated in any other convenient way.

The above methods of applying the heat for tempering are to suit those kinds of articles which have been wholly quenched. When any of the above methods of applying

the heat is adopted, and the articles are exposed to a higher degree of heat than that which is required to reduce them to the exact temper, they must be removed from the heat immediately they attain the desired color, otherwise the temper will become too far reduced, or in other words the articles will be too soft for the purpose they are intended for. After they are removed from the heat they may be immersed in water or oil, or they may be allowed to cool in the air of their own accord; for it matters not which way they become cold, providing the heat has not been too suddenly applied; for when the articles are removed from the heat they cannot become more heated, consequently the temper cannot become more reduced. But those kinds of tools which are heated further than what they are required hard, such as a large portion of the small kinds of turning tools, cold chisels, and the larger kinds of drills, and numbers of other kinds of tools, and which are only partially dipped, and which are afterward tempered by the heat from the back of the tool, must be cooled in the water the moment the cutting part attains the desired color, otherwise the body of the tool will continue to supply heat, and the cutting part will become too soft.

It is, perhaps, too obvious to require remark, unless it be for the information of those who are unaccustomed to these processes, that if, after tempering an article, it proves too hard for the purpose it is intended for, it is not absolutely necessary to reharden it, though in some instances it is more convenient to do so; the temper may be further reduced by exposing it again to heat; but, if an article is too far reduced in temper, it becomes then absolutely necessary to harden it over again. When a very large number of small articles are

required to be tempered, it will be too slow a process to temper them to a certain color; therefore, a more expeditious method must be adopted. A very convenient way of tempering a large quantity of small articles at once, and of heating them uniformly, no matter how irregular their shape, providing the heat is not too suddenly applied, is to put them into a suitable iron or copper vessel with as much tallow or cold oil as will just cover them, and then to place the whole over a small fire and slowly heat the oil until a sufficient heat is given to the articles for the temper required. It may be well, perhaps, to remind the young mechanic that the temperature of the oil or tallow may be raised to 600 degrees of heat, or rather more; consequently, any temperature below a red heat may be given to the articles by the heated oil. Certain degrees of temper retained by steel articles when they are heated in oil may be estimated by the following circumstances: When the oil or tallow is first observed to smoke, it indicates the same temper as that called a straw color. The temperature of the oil, if measured by the thermometer, will be about 450* degrees.

If the heat be continued, the smoke becomes more abundant, and of a darker color; this indicates a temper equal to a brown. The temperature of the oil at this stage, if measured by the thermometer, will be about 500 degrees. If the oil or tallow be heated so as to yield a black smoke and still more abundant, this will denote a purple temper. The temperature of the oil at this stage, if measured by the thermometer, will be about 530 degrees. The next degree of heat may be known by the oil or tallow taking fire if a piece of lighted paper be presented to it, but yet not so

*Fahrenheit.

hot as to burn when the lighted paper is withdrawn. This will denote a blue temper. The temperature of the oil at this stage, if measured by the thermometer, will be about 580 degrees. If the articles are lifted out of the vessel at this period, they will be found to possess a considerable amount of elasticity. This temper is not unfit for some kinds of springs, but only when a rather mild kind of steel is employed; the steel in this state may be wrought; that is, it may be turned or filed, though with difficulty.

The next degree of heat may be known by the oil or tallow taking fire and continuing to burn, at the same time rising higher in the vessel. If the articles are lifted out of the vessel at this period, the oil will burn upon them with a white flame. This is the temper which is mostly used for spiral and some other kinds of springs.

If the whole of the oil or tallow be allowed to burn away before the articles are lifted out of the vessel, it imparts the temper which clock makers mostly use for their work. This temper is the lowest used, when the steel is required to be at all harder than in its natural state; for a small degree of heat more would just be seen (red) in a dark place.

Any single article, to spare the trouble of heating it in a vessel with oil or tallow, may be smeared with oil or tallow and held over a clear fire, or over a piece of hot iron; or, if the article is small, it may be held in a gas flame, or in the flame of a candle, and its temper, when heated, ascertained in a similar manner. It will not, perhaps, be out of place to state, that I was once asked by a young man the way to harden and temper spiral springs made of steel wire. I informed

him that he must first of all harden them either in water or oil, according to the substance of the steel; and, if he had a sufficient quantity to do which would pay for the waste of the oil, it would be a very convenient and expeditious method to tie them all together with a piece of iron wire, and place them in an iron saucepan or any other suitable vessel he might chance to have, with as much oil or tallow as would cover them, and then to place the whole over a small fire, and slowly continue the heat until the oil takes fire, and continues to burn; after which, to lift the springs out of the vessel by means of an iron rod, and then to give them one dip into some cold oil. This was to give the springs a black color; they were then to be allowed to cool in the air of their own accord.

When I gave the above information, I did not think for one moment that this young man would attempt to boil the oil over the fire in the dwelling house; but he informed me that he did so, and the result was that he nearly set the house on fire. I have just mentioned this circumstance merely as a warning to those who are unacquainted with the nature of oil at this high temperature, so that they may not fall into the same error; they must not attempt to boil oil unless they have a place suitable for it, or serious accidents may happen.

Before putting any article in the fire to heat it for hardening, it is necessary to examine its shape in order to know which way it will require to be immersed in the water so as to lessen the risk of its cracking; every kind of article requires to be dipped a particular way according to its shape. For instance, if the article is unequally thick and thin, or in other words, if there is a stout part and a thin

part, the stoutest part should always enter the water foremost. By dipping the article with the stoutest part of it entering the water foremost, it causes the steel to cool more uniformly, and lessens the risk of fracture. If the thinnest part of the article be allowed to enter the water foremost, it increases the risk of fracture, because it will become cool much sooner than the stouter part of the article, consequently the stout part of the article contracts by the loss of heat after the thin part is fixed; the thin part in its then hard and brittle state cannot give, consequently it breaks; or, if it does not break at the time of the hardening of it, it is held in such a state of tension (strain) that it is ready to break when applied to the work.

Though it is requisite when hardening steel articles to let the stoutest part of the articles enter the water foremost, in order to allow the steel to become cool more uniformly, still it is not practicable in all instances to get the stoutest part of the articles into the water foremost, as will subsequently be shown.

When it is not practicable to get the stoutest part of some kinds of articles into the water foremost, some other method which will keep the thin part of the articles from cooling too suddenly, and which will cause the steel to become more uniformly cool, must be resorted to. The various methods to be adopted for lessening the risk of fracture when hardening various kinds of articles, will be explained as we go along.

The water which is to be used for hardening steel tools, or any other kind of articles made of steel, should never be quite cold, but should have, as the term is, the chill taken off, or, to use other words, the water requires to be made a few degrees warmer. The reason for this is, that when

water of too cold a temperature is used, it abstracts the heat so suddenly from the surface of the steel that it causes a too sudden contraction of the surface steel, and the expansion of the interior steel in its still red-hot state is more than the hardened crust can bear, consequently it frequently causes the steel to break.

It is quite probable that the interior steel for the moment becomes both heated and expanded in a higher degree by the sudden compression, for the sudden contraction of the surface steel by the sudden loss of heat must act on the interior steel something similar to a blow from a heavy hammer or the pressure of a squeezer; and if the steel should happen to be a little too hot at the time of dipping it into pure cold water, there is as much danger of its breaking as there is of a glass bottle breaking when boiling water is poured into it; heat and cold act on glass and other brittle substances in a similar manner that they act on steel. When boiling water is poured into a glass bottle, the expansion of the inside glass is so sudden that it is more than the outside can bear, consequently the bottle breaks; if the glass is heated to a red heat and plunged into cold water, it breaks into a quantity of small pieces from the sudden contraction; if a stone is thrown into the fire, it breaks from the sudden expansion of its surface.

The more the water is used for hardening steel the softer it becomes, and has a tendency to act less suddenly upon the steel; consequently, the less frequently the water used for the purpose is changed the better it is for hardening the steel that is, providing the water has not by continual use become greasy. The water is not made better for giving the steel a greater degree of hardness by being long in use, but

it is made better for the purpose because it is less likely to crack the steel than fresh water; therefore, as the water wastes, fresh water should be added to it. As it is necessary to clean the tank out occasionally, it would be well before using fresh water to make it quite hot, by putting bars of hot iron into it and allowing it to become nearly cold again before using it, or the chill may be taken off the water and the water made softer by putting some ignited charcoal or wood ashes into it. It is obvious that the colder the water the more effectually it hardens the steel, and the more especially when the steel is immersed suddenly and a rapid movement is given to it while it is becoming cool; but when fresh cold water is used there is always greater danger of the steel cracking. Brinish liquids, such as aquafortis, urine, or water charged with common salt, etc., produce rather more hardness than plain water; but, for most articles, plain water with the chill off gives sufficient hardness to the steel. Water at about sixty degrees measured by the thermometer is the most suitable temperature to prevent steel cracking in hardening. Water holding soap in solution prevents the steel from hardening. There are certainly some kinds of tools, also some pieces of work used in machinery, which require to have a greater amount of hardness given to them than can be given by plain water; there are some kinds of gauges, burnishers and certain kinds of dies which require to be very hard, so that it becomes necessary at times to use a saline liquid; a file requires also to have a nice hard tooth. When steel is required to be made extremely hard it may be quenched in mercury (the chemists' name for quicksilver), but this fluid it is obvious can only be used on a small scale.

All bright articles which are made of steel, and which require to be hardened, are the better for being heated, previous to immersion, in contact with carbon. By heating steel in contact with carbon, or by supplying a small quantity of carbon to the surface of the steel after it is heated, it favors the steel in hardening; but, though it is better to supply a small quantity of carbon to the surface of the steel, still it is not absolutely necessary to do so, because very satisfactory results are obtained with some kinds of articles by heating them in red-hot lead previous to immersion. When red-hot lead is used as a source of heat, the method of supplying carbon to the surface of the steel cannot conveniently be adopted; neither can the method of supplying carbon to the surface of the steel be conveniently adopted when some other methods of heating steel are adopted, such as heating some small steel articles between the heated jaws of a pair of tongs, or between two heated pieces of bar iron, or in a gas flame, the flame of a candle, etc. To supply carbon to the surface of steel articles, the articles may be inclosed in a sheet-iron case or box, and surrounded on all sides with either wood charcoal or animal charcoal; the whole will require to be placed in a furnace or hollow fire and heated to redness. Wood charcoal is too familiar to every one to require remark in this place; but it may be necessary to state that the animal charcoal here spoken of is nothing more than any animal matter—such as horns, hoofs, skins, or leather, etc., just sufficiently burnt to admit of being reduced to powder. If it is found more convenient to heat the articles in the midst of the ignited fuel of an open or hollow fire, it is advisable to do so; but when any bright steel article is heated in an open or hollow fire, free of wood

or animal chárcoal, it ought always to be coated with prussiate of potash, or some other substance which will, after it has arrived at a red heat, protect it from the direct action of the fire and water, at the same time supplying a small portion of carbon to the surface of the steel. Though bright steel, when heated in the midst of the ignited fuel of a hollow or open fire, is the better for being coated with the prussiate of potash, still there are instances when it will be advisable not to use it; for instance, if the potash were used in hardening saws which require to be sharpened with the file, it would cause greater difficulty to file them; consequently, in such an instance, the potash should not be used. When it is required to coat any steel article with the prussiate of potash, the article will require to be heated to redness before the potash is put on to it, otherwise it is useless to put it on, for the steel requires to be sufficiently hot to fuse the potash when first it is applied for the potash to be of any practical service to it. The potash should always be finely powdered and placed in a small box, the lid of which should be full of small holes, similar to a grater or pepper-box. The reason for this is that it is the most economical way of using it, especially if the article is held over a piece of plate iron whilst the potash is being put on; what portion of the potash falls upon the plate must be returned to the box, and thus prevent it being wasted.

After heating any steel article to redness and sprinkling the potash upon it, it must be returned to the fire for a few minutes, or until it attains the desired heat; the article is then ready to be immersed in the water. Sometimes when the article is very large it is necessary to draw it from the fire a second time and sprinkle it again with the potash, in

order to give it a thicker coat before it is immersed in the water.

Steel which is hardened with the skin upon it, will undoubtedly be the better if it be sprinkled with the prussiate of potash; for it has always a tendency to penetrate through the thin oxide, and supply carbon to the surface of the steel, which, perhaps there is no necessity for repeating, is favorable to the steel in hardening.

It may be well to state that the access of air to the potash should always be prevented, when the potash is not in use.

Steel in the state it leaves the forge, with the skin or thin scale upon it, is less liable to break in hardening than steel which is brightened previous to hardening. The skin or thin scale upon the steel prevents the water from acting too suddenly upon the steel; consequently the contraction is slower. Common turning tools will always stand better; that is, they will keep a finer and firmer edge, if they are hardened with the skin upon them, than they will if they were brightened (either by filing or grinding) previous to hardening; in fact, all tools that can be ground and sharpened upon the grinding stone after they are hardened, will be the better for being hardened with the skin upon the steel; and, if properly forged by the tool smith (who is generally as well acquainted with the proper shape of tools as the mechanic who uses them), the tools will require very little grinding; and as for water cracks in the steel, there will be none. When turning tools are made of the best cast-steel, and hardened previous to the removal of the skin or scale, and which are not intended to have very keen edges but which are intended to sustain a good hard edge for cutting iron and other metals (cast-iron especially), they will

not require to be tempered after being made hard, but the heat should be carefully regulated at first, as the most useful hardness is produced by that degree of heat which is just sufficient to effect the purpose; for it is quite reasonable to suppose that the hardness of steel depends upon the crystallization, and the intimate combination of its carbon; therefore, the heat which effects this must be the best.

As there are a number of tools used in the turnery which cannot be ground upon the grinding stone, owing to their peculiar shapes, it becomes necessary then, while the steel is in its soft state, to fit these kinds of tools up with the file, or to form them in the lathe, or some other machine; consequently these kinds of tools cannot be hardened with the skin upon them. But, as there is greater liability of brightened steel breaking in hardening than that which is not brightened, and as some kinds of tools cannot be ground after they are hardened, it becomes an object of importance that they should stand well. Therefore, extra precautions must be used when hardening these kinds of tools; for, were their cutting edges to chip through being a little too hard, or rub off through being a little too soft, they will be practically useless for the purpose they are intended for, until they have been softened and fitted up again, and subsequently hardened. In some instances the tools would be wholly useless; this would be the case with screw taps, and some kinds of reamers, broaches, etc., for their original sizes would be lost. It must be obvious, then, that if extra care is required with some kinds of tools, it must be with those kinds which take a great amount of labor and time to make them; also with those kinds which cannot be repaired.

It is well known that, when iron is heated to a high temperature, and forged upon the anvil, a thick unequal scale is formed upon the surface of the iron, by the action of the oxygen of the atmosphere; and if steel is heated to the same degree, and forged upon the anvil, a thick unequal scale is formed upon its surface in a similar manner as it is formed upon the surface of iron. This thick unequal scale would cause the steel to harden unequally, if it were not removed previous to hardening of the steel; but it must be borne in mind, that, when tools are made of the best cast-steel, and forged at the proper heat, and the anvil kept clean during the time they are forged, it will prevent this thick unequal scale being formed; but a very thin equal skin or scale will be formed. This thin equal scale does not prevent the steel hardening equally, neither does it prevent the steel becoming sufficiently hard for most purposes; but it will prevent the surface steel becoming cool too suddenly, consequently it must be obvious that it will have a tendency to prevent the steel breaking in hardening.

When steel is required to possess the greatest possible degree of hardness, it is obvious that the scale must be removed previous to hardening of it.

There are many large steel articles broken after hardening them, by taking them out of the water before they are thoroughly cold; and, perhaps, a few words upon this will not be out of place. It is the opinion of many mechanics that the cause of steel breaking after it is lifted out of the water is the action of the air upon the steel, when first the steel comes in contact with the air. It is true that large masses of steel frequently break immediately the steel is lifted out of the water; but I am at a loss to see in the

slightest degree what effect the air can have upon the steel in this instance. My opinion is this, and which I have formed from experience, that if the steel does not break during the time it is becoming cool, there is no more danger of its breaking after it is lifted out of the water than what there was of its breaking in the water, that is, providing the steel be allowed to remain in the water until its center becomes quite cool. During the time the steel is in the water becoming cool, and after a certain amount of heat is abstracted from the outer crust, there is a peculiar motion or vibration of the interior particles in rearranging themselves according to their form. This peculiar motion weakens the cohesion of the particles. The tension of the steel at this period is in one direction; but let the steel be lifted out of the water before the central steel has become quite cool, and the tension is reversed in an opposite direction. This is caused by the central steel imparting heat to the inner side of the hardened crust; and this sudden change is frequently more than the hardened crust can bear, and causes the steel to break. If the steel does not break, it is held in such an unequal state of tension, from the particles not being allowed sufficient time, before they were again disturbed, to assume the exact arrangement to which they are naturally disposed, that the tenacity of the steel must more or less be weakened. It is not requisite that the steel should lie in the hardening tank until the steel and the water become quite cool; for in some instances the steel article is required for immediate use. In such instances, any vessel, such as a hand bowl or a water bucket, etc., may be sunk into the tank, and the steel article or articles may, while the vessel is under the surface of the water, be lifted into the vessel; after which the vessel

can be lifted out, with as much water in it as will cover the article or articles. The vessel may then be sunk, with the article or articles still in it, into another tank of quite cold water, or the vessel may be placed under a water tap, and cold water run upon the articles; and when they are quite cool they can be lifted out with safety. It will be obvious that the greater the mass of steel the greater the risk of its breaking by being removed from the water before it is thoroughly cold.

There are many articles cracked in hardening by heating them all over, or throughout their body, and then partially dipping them into the water. All kinds of articles which are heated all over are the better for being dipped and hardened all over; and then, if one part of the article is required softer than the other parts, it is best to soften it after. To spare this trouble, at the same time lessen the risk of fracture, it will be well not to heat some kinds of articles in any other part but that which is required hard, and then to entirely quench them. The heat of course must not terminate upon the article in a strict line, but should be gradually tapered off. It is obvious that the heat will not terminate in a strict line when the article is heated in a common smith's fire; but, when red-hot lead is used as a source of heat, the heat upon the article is liable to terminate in a strict line unless a vertical movement be given to the article. If only a certain part of a steel article is required to be hardened, and the article be heated throughout its body, and the water into which the article is to be put be quite cold, and the hardener in dipping it stop at any particular part, at the same time holding it quietly without giving it a movement while it is becoming cold, there is always great danger

of the article cracking at the very spot which is level with the surface of the water; and sometimes the article will break asunder at the particular spot as evenly as though it had been cut with a saw. The tools required by the millwright, pattern maker, carpenter, joiner, and cabinet maker are those kinds of tools which are generally attended with the greatest risk by being heated throughout their body, and only immersed half their depth into the water; especially the small and middle-sized varieties of the best kinds, which are always made wholly of the best cast-steel, and which are generally filed or ground bright, and fitted to shape previous to hardening. The tools required by these different artists do not differ so much from each other in construction and name as in size, though the very large tools used by millwrights, carpenters, and others for heavy, coarse work are generally composed of iron and steel welded together, the steel forming but a small portion of the whole mass of metal. With these kinds of large tools there is less risk of fracture in hardening, because it is generally shear steel or a mild kind of cast-steel (steel containing a smaller proportion of carbon) which is used for welding to the iron. It is obvious that if the steel be properly welded to the iron, a flaw will be less likely to occur, and a rupture more difficult to start.

From these statements the reader may, perhaps, be inclined to think that I am condemning the method which is so much practiced in the art, that of partially dipping the articles and afterward tempering of them by the heat at the back of the tool or article; but it is not my object to condemn a method which I know from experience to be in a considerable number of instances very convenient and very economical; but knowing from experience that certain

kinds of articles are so liable to crack when the method of partially dipping them is adopted, I have made it my object to state the cause of their cracking, and to give such remedies as will, in a great measure, prevent these water cracks. When the method of partially dipping a steel tool or other kind of article is adopted, the article may generally be prevented from cracking by simply putting the water in motion previous to dipping the article, or by giving the article a quick movement when it is in the water as far as it is required hard; either of these methods will prevent the water from acting so evenly in cooling it in a strict line; either of these methods causes the line between the hard and soft part of the article to occupy more space, and lessens the risk of fracture. Water cracks may also be prevented in that part of any article which is required to be level with the surface of the water, by simply coiling a piece of binding wire round that particular part, and when sufficiently heated, coating it with the prussiate of potash previous to immersion. This method prevents the water from acting so suddenly or evenly upon the steel, at that particular part of the article; consequently it prevents its cracking.

Chipping chisels, drills and all other kinds of tools which are only partially dipped into the water, should never be held still while they are becoming cold; but they should, after they are dipped to the required depth, have a sudden vertical or other movement given to them. I have no doubt that many have noticed when they have been chipping that their chisels have sometimes broken off about an inch or rather more from the cutting edge, or at that part of the chisel which was level with the surface of the water when it was hardening. The cause of the chisels breaking in this par-

ticular spot arises in a great number of instances from the chisels having been held quietly in the water when hardening. The water cooling them across in a straight line causes the hardened part to tear from the soft part, and the chisels sometimes break with a very light blow of the hammer, and sometimes with the very first blow. I have myself witnessed the ends of drills drop off by simply dabbing their points into the wooden bench. I have also witnessed the ends of drills drop off at the grinding stone when they were being sharpened, after having been repaired. I have also witnessed the ends of drills drop off on the slightest application to the work; and from no other cause but from the drills having been held quietly in the water when hardening. But, as these kinds of articles are generally hardened with the skin on the steel, they are less liable to break than articles which are brightened previous to hardening. I recollect once having a quantity of small flat drifts to harden, which had triangular grooves cut in them, to form sharp cutting edges, something similar to a file, but cut coarser and deeper, and I was requested to leave the top part of them (called the heads) soft. So I put a certain number of them into an iron box and surrounded them on all sides with charcoal dust; luting the box with clay, I placed it in a hollow fire and slowly heated the whole to redness, after which I opened the box and let the contents drop from the box into the water tank, with the intention of subsequently softening the heads. After taking them out of the water and examining them, I found a number of them very crooked; this was owing to their being so slight and going from the box so suddenly into the water. As these kinds of tools are required for clearing, truing, and finishing holes, it is obvious that this

defect of being crooked is very detrimental, for these tools cannot produce true work if they are crooked, besides, they are more liable to break when they are struck with the hammer than if they were straight.

As the above method did not afford a very satisfactory result, I adopted another method. I placed a certain number of them in a sheet-iron pan without a lid upon it; I surrounded the drifts with charcoal dust, the same as previously, and heated the whole to redness in a hollow fire; as they became heated I gripped separately the head of each drift with the pliers, and dipped it endways and perpendicularly and slowly into the water. This method had the effect of causing them to keep straight and answering the purpose so far, but it took a longer time to dip them separately; so thinking to save this extra time, I thought I would only dip them in the water as far as they were required hard, and that would save the time and trouble of softening the parts which were not (according to order) to be made hard, namely, the heads of the drifts. But not caring about going ahead with any large quantity until I made myself sure that all was going on well, after I had dipped about two dozen of them, I thought it necessary to examine them, and I did not find one of them but what was cracked at that part of the drift which was level with the surface of the water when hardening them; so I dipped the remainder of them all over, and separately, and hardened them throughout, and not a crack appeared in one after. After tempering them to the proper temper, I made some lead red hot in an iron ladle and dipped the heads that were to be soft into it, and accomplished my object very nicely.

This tearing of the particles from each other when the hardening terminates in a strict line is not at all times sufficient to cause the steel to break asunder, neither is it at all times sufficient to show signs of fracture; but whether the steel breaks asunder or not, or whether there are signs of fracture or not, this tearing of the particles from each other when the hardening terminates in a strict line, must always with highly carbonized steel more or less take place, when it is known that hardened steel occupies more space than soft steel, and that the density of the steel is different in the two states.

When it is required to harden large circular cutters which have teeth round their circumference, or large cutters having teeth on their sides as well as on their circumference, or, I may state, such cutters as those which have previously been treated of, they may be enclosed in a sheet-iron case or box and surrounded on all sides with either wood charcoal or animal charcoal. The box will require to be luted with clay or loam, and the whole placed in a furnace or hollow fire and heated to redness. A certain amount of time is essential to allow the steel to soak, or, in other words, to get heated uniformly throughout. After the cutters are properly heated they must be lifted out of the box separately, not by the tongs or pliers, as they are apt to spoil the sharp cutting edges of the cutter, but by a rod of iron (the poker) put through the spindle hole of the cutter. The hardener must be provided with a proper tool for bearing the cutters while he dips them into the water, as the pliers do not answer well for this purpose. The most suitable tool for dipping the cutters is made by taking three pieces of round iron about ¼ of an inch in diameter and 3 or 4

inches in length. Grip the three pieces at the end with the tongs and weld the three opposite ends together, after which the welded end must be scarfed and welded to the end of another piece of iron, about ¼ of an inch in diameter and about 18 inches in length: this forms a stem with three prongs at one end of it. The three prongs must be turned back so as to stand at right angles with the stem; so that when the stem is put through the spindle hole of the cutter and gripped with the hand, the cutter will lie upon the three prongs. A kind of ring or loop should be turned at the end of the stem to keep the stem from slipping through the hand by the weight of the cutter, but the loop must be sufficiently small to pass through the spindle hole of the cutter.

It may be inquired, will not a long bolt, with a large flat head, answer the same purpose as a stem with three prongs at the end of it? The answer to this is: it would answer quite as well as regards the bearing of the cutter, but the large flat head would prevent the water from passing freely through the spindle hole of the cutter, and would thus prevent the cutter from cooling uniformly. After the cutter is lifted out of the box, this wire stem must be put through the spindle hole of the cutter and gripped with the hand; and while the cutter rests upon the three prongs it must be immersed into the water, and instead of moving the cutter backward and forward in the tank, it should be moved up and down so that fresh water is continually passing through the spindle hole during the time the cutter is becoming cool. The deeper the tank the better it is for the purpose. Care must be taken while moving the cutter up not to allow it to come above the surface of the water, or it will be liable to crack.

Should the tank not be sufficiently deep to allow moving the cutter up and down, the cutter may, after it is beneath the surface of the water, be turned sideways, and while one end of the wire stem is gripped with the right hand the opposite end can be gripped with the left hand. The cutter can easily, while it is beneath the surface of the water, be shifted toward the middle of the wire stem, which will keep the cutter or the heated water as it passes through the spindle hole of the cutter from burning the hands. It is advisable to keep the cutter moving until it is sufficiently cool to be gripped with the hand. If more than one cutter has been heated, the wire stem must be taken out of the water, as it will be required for dipping the other cutters. There is no necessity for removing the first cutter from the water until all the cutters that have been heated have been immersed; but, if the first cutter has increased the temperature of the water too high, more cold water should be added to it before the second cutter is immersed, and so forth, if necessary, until all that have been heated have been immersed. The cutters may, after they are hardened, either be allowed to remain in the water until the water is thoroughly cold, or they may be lifted out of the water by the method previously explained. If the cutters are uniformly heated and immersed in the water, in the manner just described, they will keep their proper shape better than by any other means; while they are much less liable to crack, because they cool more uniformly. Any size cutters, dies, bushes, rings, or collars, or ring gauges, may be heated and immersed in the water in the same manner as circular cutters. It will be obvious that gauges or dies which have no holes, or which have only a small hole through them, cannot be dipped with the same kind of tool

as circular cutters, consequently the pliers will be quite suitable for gripping these kinds of articles. It is not absolutely necessary that circular cutters, dies, bushes, rings, gauges, etc., should be enclosed in a box to heat them, neither is it absolutely necessary to surround them on all sides with wood or animal charcoal, as it will answer equally as well, and be a far more expeditious method, to carefully and slowly heat them in the midst of the fuel of a hollow fire; but when these kinds of articles are heated for hardening in the midst of the fuel of a hollow fire, they should always be coated with the prussiate of potash. Dies having engraved surfaces are undoubtedly the better for being heated in a box and surrounded with wood or animal charcoal; because it would not answer very well to fill the fine engraving with the prussiate of potash, neither would it answer to heat them in contact with the air. The method of enclosing these kinds of articles in an iron box, and surrounding them on all sides with wood or animal charcoal, answers three good purposes: it causes the heat to be very slowly and equally applied; the surfaces of the dies are rendered rather more steely by the absorption of carbon, and it prevents the scaling occasioned by the contact of the air. If the dies or any other kind of steel articles be previously polished, and well defended from the air, they will be, when hardened, nearly as clean as before. Small cutters, after they are hardened, require to be brightened in one, two, or more places, and tempered to a yellowish white or light straw color. A very good way of applying the heat for tempering most kinds of circular cutters is to place the cutter upon a piece of round bar iron. The most suitable piece of iron for the purpose is made by slightly tapering several inches of a piece of round bar iron.

The size of the iron, previous to drawing the taper upon it, should be a little larger in diameter than the diameter of the spindle hole of the cutter; so that, if it is necessary (while tempering the cutter) to draw the cutter upon the stouter part of the iron, so that the iron may fit the hole tightly and supply more heat, it may be done. To temper the cutters by the use of this piece of iron, the tapered end of the iron will require to be heated to redness; it must then be put into the spindle hole of the cutter, the iron and the cutter must be supported with the left hand, while a slow rotary motion is given to the cutter, by the use of a small stick of wood, with the right hand. This method will equalize the heat, and cause the temper to be more uniform. As soon as the light straw color appears upon the brightened parts of the cutter, it must be removed from the heat; after which it may be immersed either in water or oil, or it may be allowed to become cool in the air, for it matters not (after it is removed from the heat) which way it becomes cool—that is, providing the heat has not been too suddenly applied. Though this is the most suitable method for applying the heat for tempering most kinds of circular cutters, still there are some kinds of circular cutters requiring to be tempered after they are hardened, where it will be found more convenient to temper them upon a piece of flat bar iron, heated to redness. The heat must not, in any instance, be too suddenly applied. It is advisable, in some instances, when tempering some kinds of circular cutters upon a piece of flat bar iron, to place a piece of cold plate iron between the cutters and the red-hot bar, in order that the heat may be more slowly and equally applied. It will be found necessary, when tempering some kinds of circular cutters upon a piece

of flat bar iron, to turn them over occasionally during the time they are becoming heated, so as to expose their opposite sides to the heat, and thus impart to the cutter a more uniform temper. The yellowish white or light straw color gives tenacity to the steel without materially reducing its hardness; it also lessens the risk of small cutters breaking when in use. There is no necessity for tempering or reducing the hardness of the largest size circular cutters; because, owing to the larger body of steel, they are much longer than the smaller size cutters in becoming cool. A larger quantity of steam is also formed at the sides of the large cutters, which prevents the water, for a few moments, from acting upon the steel; consequently, the largest size cutters cannot become so hard and brittle as the smaller size cutters. The hardness, of course, depends, in some measure, upon the quality of the steel; likewise the temperature of the water and the temperature of the cutters when they are immersed in the water. If the quality of the steel, from which large and small cutters are made, be equal, and if the temperature of the water in which the large and small cutters are immersed be equal also, and if the large and small cutters be equal in temperature when they are immersed, this variation in the hardness of the largest and smallest size circular cutters, for the reasons just given, must certainly take place. It will be obvious, then, that if the smallest size cutters require only to be reduced in temper to a yellowish white or light straw color, that the largest size cutters will not, after hardening, require to be tempered; but the hardening strain may be made more uniform throughout the body of large cutters by boiling them in water for several hours.

Dies which have engraved surfaces, after they are hardened, require to be tempered; not because the engraved surfaces of the dies are too hard, but because the whole body of the steel requires to be toughened, in order to better fit the dies to withstand the continual hardship to which they are generally exposed when in use. To temper these kinds of articles the engraved surface of the dies will require to be brightened; the dies must then be placed upon a piece of flat bar iron, several inches of which must be heated to redness. If it is required to temper a quantity, several may be placed at once upon the bar. Care must be taken that all the dies may not arrive at the proper temper at the same moment. The dies should not be placed upon the hottest part of the bar at first; but they should, as they become gradually heated, be pushed upon the hotter part of the bar. The dies will require to be moved occasionally during the time they are becoming heated in order to equalize the heat. As soon as a light straw color appears upon the brightened surface of the dies, they must be removed from the hot iron; and, if the heat has not been too suddenly applied to them, they may be allowed to cool in the air of their own accord. If the heat has been too suddenly applied, and has changed the under side of the die or dies to a deep blue color, it will then be requisite to cool them either in water or oil, otherwise the bottom side of the die, after it is removed from the hot iron, will continue to supply heat to the engraved surface and reduce the hardness too much; and the die or dies will be practically useless for the purpose they are intended for, until the operations of hardening and tempering of them have been repeated.

Hardening these kinds of articles a second time without hammering them increases the risk of their breaking; and as they cannot be hammered without spoiling the engraving, it must be obvious that very great care is required when hardening and tempering them, and the hardener ought never to place more of the dies upon the hot bar than what he can conveniently manage.

When it is required to harden steel rings or collars which have one thick edge and one thin edge, such as the collars of some turning lathes, these may be enclosed, several at once, in a sheet-iron case or box, and surrounded on all sides with either wood or animal charcoal. The box will require to be luted with clay or loam, after which the whole may be placed in a furnace or hollow fire, and the steel rings or collars heated to the proper temperature suitable for hardening them. To spare the trouble of enclosing these kinds of articles in a box and surrounding them with charcoal, they may be heated in a suitable furnace without being enclosed in a box, or they may be heated in the midst of the fuel of a hollow fire. When these kinds of articles are heated in a furnace or hollow fire in contact with air, and the fire free of wood or animal charcoal, they should always be coated, previous to immersion, with the prussiate of potash, in the manner previously explained. When the rings or collars arrive at the proper temperature suitable for hardening them, they must be drawn from the fire and placed upon the same or a similar kind of wire tool as that which is used for bearing circular cutters, while they are becoming cool when they are immersed in the water. The rings or collars may be immersed in the water separately, or two or three may be immersed at once, by taking care to

place them upon the wire in such a position that the stoutest edge of each ring or collar may enter the water foremost. Previous to immersing these kinds of articles in the water, and when it is intended to place two or three of them at once upon the wire to be immersed together, it will be necessary to examine the depth of the water in the hardening tank, in order to ascertain whether the depth of the water is sufficient to allow the rings or collars when immersed being moved up and down without risk of bringing a part of the uppermost collar above the surface of the water. If the water is not sufficiently deep to allow these kinds of articles, when two or three are immersed together, being moved sufficiently to remove the heated water from the inside of them, it will be far better to immerse them separately, and thus lessen the risk of their breaking. These kinds of articles require to be very slowly and uniformly heated, and should not be plunged too suddenly into the water. The more uniform the temperature the less liable are they to become oval or out of shape, and the more uniform they become cool the less liable they are to crack; consequently, it must readily be seen that these kinds of articles require to be immersed very slowly. It must also readily be seen that it is quite requisite that the thickest edge should enter the water foremost. The degree of heat required to harden these kinds of articles will, of course, depend upon the quality of the steel from which they are made. Sometimes rings and collars are made of the best cast-steel; they are made by punching a long hole near the end of a steel bar; after the hole is punched a round taper mandrel is driven into it to widen the hole; it is then cut off the bar near to the hole and worked upon the beak iron of the anvil. When

the ring or collar has nearly reached the proper form and size it is finished upon a larger mandrel than the first, after which it is annealed and turned in the turning lathe to the required dimensions. When rings or collars are made of the best cast-steel by the method here explained, they will only require to be heated to a low red heat to harden them.

Sometimes rings and collars are made of shear steel. They are made by scarfing the extreme end of a bar of shear steel; the ring or collar is then partly formed by bending the scarfed end of the bar round the beak iron of the anvil; the partly formed ring is then cut off the bar, and the second end is scarfed; the two ends are then brought together, and united by welding. The shear steel rings are then finished upon a mandrel; after which, they are annealed and turned in the lathe to the required dimensions. When rings or collars are made of shear steel by the method here explained, they will require to be heated to a bright cherry-red heat to harden them. Sometimes rings and collars are made of iron, and made to take the place of steel; they are made in a similar manner as the shear steel rings or collars. In order that the iron rings or collars may be made hard, and take the place of steel, they are, after they are finished being turned in the lathe with the exception of polishing, case hardened.

It is seldom necessary to temper or reduce the hardness of steel bushes, rings, or collars, because the generality of these kinds of articles are required for bearings for different parts of machinery, where they have to endure a great amount of friction; consequently they require to be very hard to keep them from wearing. Ring and plug gauges,

which are made of steel, require a great amount of hardness given to them to prevent them from wearing; consequently these kinds of articles will not, after hardening, require to be tempered.

Ring and plug gauges are sometimes made of iron, and made to take the place of steel by being case hardened, previous to lapping or grinding to their proper sizes. The method of case hardening will be explained in a subsequent chapter.

It has already been shown that the more uniformly steel articles become cool when hardening, the less liable are they to fracture; and it has been previously recommended that the stoutest part of steel articles should enter the water foremost. It becomes necessary, perhaps, to state here, that this method of immersing steel articles cannot in all instances be adopted; for there are no means by which the stoutest part of some kinds of articles can be made to enter the water foremost. For instance, with such an article as a feather-edge circular cutter it is not practicable to get the stoutest part into the water first; consequently, when this method cannot be adopted, some other which will have a tendency to cause the steel to cool uniformly must be resorted to. It will be obvious that the method of fitting a piece of flat iron to the thinnest part of this kind of article cannot conveniently be adopted. The process of concaving the sides to reduce the substance of the steel in that part of the cutter which is the last to become cool cannot be adopted, because this would unfit a feather-edge cutter for the purpose for which it is intended. It is evident then, that if none of these methods can be adopted with a feather-edge circular cutter that there is great risk of the largest kinds breaking

from unequal cooling. When it is required to harden a large feather-edge circular cutter, it must be very slowly and uniformly heated to a cherry-red heat; the most convenient way of heating it is in the midst of the fuel of a hollow fire. As soon as the temperature of the cutter is sufficient to fuse the prussiate of potash, it must be taken out of the fire and coated with the potash, and then be returned to the fire for a few minutes, or until it acquires a cherry-red heat; after which it must be drawn out of the fire, and immersed in the water in a similar manner as other kinds of circular cutters. It will be obvious, from previous remarks, that if the temperature of these kinds of large cutters be properly regulated at first, they will not, after hardening, require to be tempered.

Previous to putting this kind of cutter into the fire, it will be well to cut out two rings from a piece of wire cloth, and bind one of them upon each side and at the thin part of the cutter. Several short pieces of binding wire will be required for binding the wire rings upon the cutter. These wire rings will not prevent the thin part of the cutter from hardening, but if they be properly bound upon the cutter they will have a tendency to cause the potash to cling more firmly to it, and prevent the water from acting too suddenly upon the thin part of the cutter, thereby causing it to cool more uniformly. It will not be necessary to bestow this trouble upon the smaller size cutters of a similar shape; but, with large, expensive cutters, to lessen the risk of fracture is not labor lost.

It occurs to me, also, that the use of the wire rings may be dispensed with by taking a certain portion of the prussiate of potash and mixing with it a certain portion of flour

or bean meal, or some similar substance, and, after heating the cutter to redness, and giving it one coat with the pure prussiate of potash, to give the thin part of the cutter a second coat with the mixture. If this mixture adheres to the thin part of the cutter it will prevent the water cooling it too suddenly, and thus prevent the cutter breaking; but I have never given the mixture a trial myself, and cannot speak upon its value with certainty.

When it is required to harden an eccentric ring or collar, it may be heated in the midst of the ignited fuel of a hollow fire. If it is made of the best cast-steel it will require to be uniformly heated to a cherry-red heat and coated with the prussiate of potash in a similar manner as other articles, after which it must be immersed endways and perpendicularly in the water and entirely quenched. It will be obvious that there would be no difficulty in getting the stoutest part of such an article into the water foremost, but it will not answer to adopt this method in such a case. If the stoutest part were to enter the water foremost it would certainly cause the collar to cool more uniformly, and probably it would prevent the thinnest side of the collar breaking; but then, by going sideways into the water, it would cause the hole in the collar to become oval, and the outside of the collar to lose its proper shape, which would unfit it for the purpose for which it was intended; consequently it is quite requisite that a piece of iron should be fitted to the thin side of the collar (as has previously been remarked), and that the collar should be immersed endways and perpendicularly in the water.

When it is required to harden a large piece of round cast-steel in which a hole has been bored through it (such a

piece as has previously been spoken of), it may be surrounded with wood or animal charcoal in a sheet-iron box and heated either in a furnace or a hollow fire in a similar manner as other articles, or it may be heated in the midst of the ignited fuel of a hollow fire. If it is heated in the midst of the ignited fuel, it will require to be coated with the prussiate of potash. Whichever method be adopted for heating it, it will require to be heated to a cherry-red heat, after which it must be withdrawn from the fire and placed upon the same kind of tool as that which is used for dipping circular cutters—it must be immersed endways and perpendicularly in the water. During the time it is becoming cool it must be moved up and down in the water in order to allow fresh water to pass through the hole, or, in other words, to remove the heated water out of the hole; or it may, after it is beneath the surface of the water, be turned upon its side and drawn backward and forward until it is cool.

It may be inquired, What makes the difference whether the steel be moved about in the water during the time it is becoming cool, or whether it be held still, when it is known that heated water always rises to the surface? The answer to this is, that the heated water does not rise to the surface so suddenly as the heat is required to be extracted from the inside of the article; consequently it is quite requisite that it should be moved about in the water in order that the cooler portions of the water may pass through the hole and cool the article more uniformly.

It has previously been stated that it is injurious to bore holes too near to the outside edges of steel articles; but it is obvious that boring holes near to the edges cannot, with some kinds of articles, be avoided; therefore, if the hardener

is required to harden any kind of steel article which has holes in it near to the edges, it is advisable before putting the article in the fire to stop the holes with a piece of loam; this method will prevent the steel breaking at the holes. It may be useful to some who are not much accustomed to harden steel to know that if a piece of binding wire be wrapped round any part of a steel article, and a piece of loam wrapped round the wire, it will prevent the steel from hardening in that part when it is immersed in the water; consequently it will prevent the steel breaking at the part where the loam is on. The wire is for no other purpose but to prevent the loam from falling off; the loam requires to be dried upon the article before it is put into the fire, otherwise it will probably crack and let the water get at the steel. But for the sake of making this subject properly understood, as it may often prove very useful to the hardener, let us suppose that the middle part of a piece of one inch square cast-steel is required to be hardened and the two ends required to be kept soft. We will suppose it to be 4 inches in length, and at each end of it a countersunk round hole, for the reception of a bolt 3/8 of an inch in diameter, having a cheese-shaped head 3/8 of an inch in thickness, and 3/4 of an inch in diameter.

It must easily be seen, by the shape of this kind of article, that if a proper method is not adopted there will be some difficulty in hardening it to make it answer the requirement, namely, quite hard in the middle and soft at the ends, and not cracked at the holes. If this kind of article could be made hot in the middle without heating the two ends there would be an end to the difficulty; but it is obvious

that, owing to the shortness of this kind of article, this cannot be done, so that, whatever method be adopted in heating it for hardening, it will require to be heated throughout its body. Fires are sometimes made so that a very short heat may be got upon any part of some kinds of articles; but this is an article which will require a certain amount of time to soak, consequently the middle part of it cannot be properly heated in a short open fire without the two ends becoming hot; it is evident, then, that the article must be heated throughout its body. There are various methods that could be adopted in hardening this kind of article. First, it may be heated in an iron box in contact with charcoal, or it may be heated in the midst of the ignited fuel of a hollow fire; when it is sufficiently heated it may be lifted out of the fire with the pliers; one end of it must then be dipped into the water and partially cooled, after which the opposite end must be dipped and partially cooled in a similar manner. This operation is to partly cool the steel to keep it from hardening at the parts which are required soft.

When the temperature of the two ends is reduced beyond that which will harden the steel, the whole of the article must be immersed in the water and entirely quenched. A certain amount of dexterity is required in cooling the ends, otherwise the middle part of the article which is required hard will become too low in temperature to harden properly. By adopting this method, the middle part of the article is hardened and the ends remain soft. Still this method is not perfect; because the article frequently becomes cracked at the holes when cooling the ends.

Another method of hardening this kind of article is to heat it the same as before, and immerse it at once in the

water. This, of course, hardens the ends as well as the middle. The ends may subsequently be softened, though very imperfectly, by placing them between pieces of iron heated to whiteness; or, the heat may be more suddenly applied by punching a hole (the size and shape of the end of the article) in two separate pieces of stout iron, and, after heating the two pieces of iron to a whitish heat, placing the ends of the article into the holes. This method of hardening this kind of article is not perfect; because the article is liable to become cracked at the holes in hardening, and the hardness is liable to become reduced in the middle of the articles by heating the ends to get them soft.

Another method is to heat the article in a hollow fire and harden it throughout, after which the two ends may be made soft by dipping them, one at a time, in some red hot lead. This method is not perfect, because the article is liable to become cracked at the holes in hardening, and too much time is required for heating the lead for softening the ends; and, as time is money, this becomes a very expensive way. Though red-hot lead is an excellent thing for heating some articles, and would answer quite well for softening the ends of this kind, still it is quite unnecessary to make use of it in this instance.

The most convenient and satisfactory method of hardening this kind of article, is to wrap a piece of binding wire about the holes, and then to fill the holes with loam; at the same time cover the ends and the wire with the loam; this will form a small ball of loam at each end of the article; the wire is to prevent the loam falling off. After the loam is placed upon the ends it will require to be gradually dried before it is put into the fire; after the loam has become dry

the article may be placed in the midst of the heated fuel of a hollow fire; that part of the article which is not covered with the loam will require to be coated with the prussiate of potash; the potash may be put on without drawing the article out of the fire, by using a slip of iron, one end of which should be the shape of a spoon; the article will require to be heated throughout to a cherry-red heat, after which it must be drawn out of the fire and immersed in the water and entirely quenched. Those parts of the article which are surrounded with the loam, namely, the holes, will remain soft and will not crack, because the water cannot penetrate through the loam quick enough to harden the steel. I have myself had numbers of articles to harden similar in shape to the one just described, and by adopting the method of stopping up and surrounding the countersunk holes with the loam I never knew one to crack; though I have seen numbers of the same kind of articles cracked at the holes when the loam has not been used. It may be imagined, perhaps, that if one method were given for hardening this kind of article it would have been sufficient; but I have thought it necessary to mention various methods (at the same time I have stated which is the best method) in order that it may set the young mechanic thinking, and to afford him a better opportunity of judging for himself which is the best method.

It has previously been stated that sharp internal angles are unfavorable to articles which require to be hardened, and it has been hinted that sharp internal angles should be avoided; but, as they are required in some kinds of articles, and as they are often left in articles when they are not required in them, I will state that when I have an article to

harden which has sharp internal angles, I always bind a piece of binding wire in the angles of the articles, and when I have a circular cutter to harden, which has a flat key-way in it with sharp angles, I always make a kind of key, by bending a piece of binding wire backward and forward and then bind it into the key-way of the cutter. This of course does not strengthen the cutter, but it has a tendency to cause the potash to cling more firmly at the key-way, and prevents the water acting too suddenly upon the weakest part of the cutter. It may, perhaps, be thought by some that it will be better to fit an iron key into it; if an iron key were fitted tight into it, it would have a tendency, at the period when the cutter was shrinking from the hot to the cold state, to split it, as the cutter would have to compress the key, which would hold it for the moment in a greater state of tension (strain) than if the key were not there.

It has previously been stated that it is injurious to make the centers too deep or too large in some kinds of articles which require to be hardened; consequently, it will be well to remark here, that, if the hardener meet with articles that he considers have too large a center in them, it will be well to stop up their centers with a piece of loam previous to hardening, and thus prevent them becoming cracked at the centers in hardening.

When it is required to harden a large quantity of small or medium-size screw taps at once, they may be enclosed in a sheet-iron case or box, and surrounded on all sides with either wood charcoal or animal charcoal. Preference should be given to the wood charcoal on account of it undergoing no change by being exposed to heat, providing the access

of air is prevented; consequently, it can be saved and put aside to be used again. The taps will require, of course, to be packed in alternate layers, commencing with the charcoal on the bottom of the box, to the thickness of about ¾ of an inch, and finishing with a layer about the thickness of the first; the intermediate layers of the charcoal need not be more than one-third the thickness of the first and last layers. Sufficient space must be left every way for the expansion of the steel taps by the heat; otherwise, as they become heated, they will bend and damage each other. After the packing is completed and the lid of the box put on, it will require to be luted with clay or loam (in order to exclude the atmospheric air), after which, the box and its contents must be put in a suitable furnace or hollow fire, and the whole heated to a cherry-red heat. The fire must not be urged, as a certain amount of time is essential to allow the contents of the box to be uniformly heated throughout. When the whole arrives at the proper heat, the box may be drawn to the mouth of the fire, the lid removed, and each tap taken out separately and immersed endways (screw end foremost) and perpendicularly in the water; or the box may be drawn out of the fire, and the whole of the taps immersed at once direct from the box in the water. It is obvious that it is a more expeditious way of hardening to immerse them all at once. But then they are more likely to become crooked than if they were taken out of the box separately, and immersed perpendicularly and slowly into the water. If the hardening tank is made of iron, and the method of immersing the whole of the taps at once is adopted, it will be well to sink a piece of board to the bottom of the tank for the taps to fall upon; the

board should be nearly the length and width of the inside of the tank, and may be sunk by placing a piece of iron upon each end of it. If, in addition to this, a piece of iron or a brick be placed at each end, beneath the board, it will have a tendency to cause the board to spring, and scatter the taps when they are tipped out of the box, which will cause them to cool more equally. The taps will, of course, require to be packed in such a position that they will, when the box is held over the hardening tank, fall endways and perpendicularly into the water. When it is required to harden a large quantity of the largest size screw taps, they may be enclosed in an iron box, and surrounded with carbon in a similar manner as the smaller sizes. They must not, like the smaller taps, be allowed to fall direct from the box into the water, but must be taken out of the box and immersed separately; but it will be a more expeditious way to heat the largest size taps in the midst of the ignited fuel of a hollow fire, or a suitable furnace. If this method is adopted, the taps will require to be very slowly heated; but several may be heated at once. When they arrive at a cherry red heat, which is the heat suitable for hardening them, they must be taken out of the fire separately and coated with the prussiate of potash, after which they must be returned to the fire for a few minutes, or until they regain the heat lost while being coated; after which they must be taken out and immersed endways, screw end foremost, and perpendicularly in the water. This method of applying the heat may also be adopted with small quantities of small or middle-size taps. Taps hardened by this method will answer the purpose for which they are intended equally as well as if they were heated in a box surrounded with carbon.

In all cases the taps must be allowed to remain in the water until they become quite cool, after which, when taken out, and previous to using them, they will require to be tempered; but, before tempering, they must be brightened in one, two, or more places, in order that the color may be seen, and the proper temper ascertained. It will not be necessary to brighten the square tops or heads, but only the plain round parts of the taps, also one of the concave grooves which are cut along the side of the taps. After the taps are brightened, they may be tempered by exposing them again to heat. When a large quantity is required to be tempered, place as many of the taps at once as may be convenient into an oven or gas stove specially constructed; heat the taps until a dark straw color appears upon the surface of them. This temper is the best that can be given to screw taps which are required for general purposes, but those required for a special purpose, such as cutting hard cast-iron, or some kinds of steel, will then require to be tempered to a yellowish white or light straw color. As soon as the proper color appears upon the surface of the taps, they must be withdrawn from the heat. If the color does not further change after the taps are withdrawn from the heat, it is a proof that the heat has not been too suddenly applied; and the taps may then be cooled in oil, or they may be allowed to become cool in the air of their own accord. Should the color be observed to be changing from a straw color to a golden color, the taps must instantly be cooled in water; otherwise they will become too soft for the purpose for which they are intended. Cooling the taps in oil, after they are tempered to the proper color, has a tendency to prevent them rusting if they are laid aside. The greater portion of the oil, of

course, will require to be wiped off; but the taps need not be wiped quite dry. Another method by which screw taps may be tempered, is to place a piece of plate iron into and near to the mouth of any common furnace, such as those which are connected with steam boilers, etc. After the plate is placed in the furnace, several of the taps may be placed at once upon the plate, and heated until the proper color appears. The taps will require to be moved about upon the plate during the process in order to equalize the heat. As they become heated, and the proper color appears upon their surfaces, they must be withdrawn from the heat; their places may be filled up with others, and a continuance of the process may be, if necessary, kept up. It is not every person who makes screw taps that has large quantities to temper at one time, so as to require a furnace, or oven, or gas stove. The amateur mechanic seldom has more than two or three sets at most requiring to be tempered at one time. There are others who have only a few to temper occasionally, merely for the use of the shop; consequently, it will be well to explain another convenient method whereby a small quantity of screw taps may be tempered without the use of the furnace, oven, or gas stove. A small quantity of taps, after they are hardened and brightened, may be tempered by gripping the top of the taps, one at a time, with a pair of tongs, and holding them in the inside of an iron ring, heated to redness, until a dark straw color appears upon its surface. The heated ring may be placed upon the anvil or other suitable place. The screw end of the tap must be allowed to project out of the ring when first the heat is applied, otherwise the point of the tap, or the leading thread, will change its color sooner than the middle part of the tap,

and temper will be unequal. As the top or plain part of the tap changes its color, the screw part must be drawn back into the ring. If the jaws of the tongs by which the tap is gripped be previously heated to redness, it will be the better, as the heated tongs will help to supply heat, and temper the taps more uniformly. It will be obvious that if the top or plain parts of small screw taps be tempered to a blue, that they will be less likely to break when in use; consequently, the heated tongs will be very convenient for tempering the plain parts of the taps to a blue at the time that the screw part is being tempered to a straw color. The hardener ought to be provided with two rings and three pair of tongs, so that, while one heated ring and one pair of heated tongs are being used, the other ring and another pair of tongs may be in the fire becoming heated. The third pair of tongs should not be heated, but they should be ready at hand; so that, if it should happen that the heated tongs supplied the heat too suddenly to either of the taps, the heated tongs could be laid aside for a few minutes, and the tap gripped with the cold pair of tongs. With care, two, and sometimes three of the smallest or the middle-size taps may be tempered without reheating the ring. The larger the diameter of the tap, the longer it will be in changing its color, that is, providing the heat is properly applied. The thickness of the iron from which the ring requires to be made must be in proportion to the thickness of the tap; or, in other words, the larger the diameter of the tap the thicker the ring will require to be, in order that the ring may retain sufficient heat long enough to temper the tap. The diameter of the inside of the ring will require to be about 2 inches larger than the diameter of the tap. If smaller than this, it will be

apt to supply the heat too suddenly to the tap. The length of the ring will require to be about the same length as the tap, except when the ring is required for tempering very long tapered taps, such as those sometimes required to have the screw part as much as 5, 6, or more inches in length. When the ring is required for tempering these kinds of taps, it will be more convenient to have it somewhat shorter than the tap, and move the tap to and fro in the ring.

The hardener will find in practice that if two or three short rings be heated and placed in a line with each other, and made to take the place of a long single ring, it will be more convenient for tempering these kinds of taps.

Screw taps are sometimes required for some purposes as much as 18 and more inches in length, the screw part occupying but a small portion (about 3 inches) of the whole length of the taps. When it is required to harden these kinds of taps, they may be placed in the midst of the ignited fuel of a very small hollow fire; or they may be placed in the inside of a piece of iron pipe, the iron pipe being previously placed in the midst of the fuel of an open fire. The screw part of these kinds of taps is the only part which requires to be hardened; consequently it is the only part necessary to be heated. They must be very slowly and uniformly heated to a cherry-red heat, and immersed endways and perpendicularly in the water and entirely quenched. These kinds of taps will, like the other kinds, require to be brightened and tempered. The plan of applying the heat by the use of an iron ring will be very convenient, but the method of gripping the taps with the heated jaws of a pair of tongs, it will be obvious, cannot conveniently be adopted; consequently, if

they be stout taps, a very thick ring heated to whiteness will be required. The whole of the screw part, and about 1½ inches of the plain part of the tap, must be allowed to project out of the heated ring, in order that the heat may be applied to a certain portion of the plain part of the tap first; otherwise the tap cannot be properly tempered. This part of these kinds of taps requires to be in contact with a greater amount of heat than will at first sight be readily imagined, and it is for this reason that I have suggested a very hot ring. If the diameter of the inside of the ring be somewhat smaller for these kinds of taps than for other kinds, it will not be amiss. As soon as this part of the tap (which is in the ring) has changed its color to any of the intermediate colors between a light straw and a deep blue, the screw part of the tap which is now projecting out of the ring must be drawn back into the ring, and tempered to the same color as the other kinds of taps, namely, a dark straw color.

When it is required to harden master taps (commonly called by workmen hobs), the same methods adopted with other kinds of taps must be applied, with the exception that these kinds of taps must be left, in a slight degree, harder than the other kinds. The reason for this is, they are mostly required for cutting steel, such as the threads of screw dies, also for cutting the threads upon those kinds of screw tools called chasers, etc.; consequently the small and middle-size master taps will not require to be reduced in temper lower than the yellowish white or light straw color. It will be obvious from the manner in which master taps are grooved, that there is greater liability of their breaking in hardening, and less liability of their breaking when in use, than the other kinds of taps of the same diameter; conse-

quently, when it is required to harden the largest size master taps, the heat should be carefully regulated at first, so that, after they are immersed in water, become cool, and taken out, they will be ready for use, and thus dispense with the subsequent process of tempering. The largest size master taps will be the better (whether heated surrounded with carbon in an iron box, or whether heated in the midst of the fuel of a hollow fire) if they are coated with the prussiate of potash previous to immersion.

When it is required to harden large or small screw dies, in large or small quantities, they may be heated in a similar manner as screw taps, either by inclosing them in an iron box and surrounding them with carbon, and placing the whole in a furnace, or by placing them in the midst of the ignited fuel of a hollow fire. Whichever method is adopted, they will require to be uniformly heated to a cherry-red heat. They will require to be immersed plain end foremost in the water; or, in other words, the screw part of the dies should be uppermost when the dies enter the water. It will be obvious that, if the dies are immersed separately, there will be no difficulty in making the plain end of them enter the water foremost; but in order to approach this method as near as practicable, the dies should be packed in the box in such a position that they will all have a tendency (when the box is opened and held over the water tank) to fall plain end foremost into the water. When the dies are heated in the midst of the ignited fuel of a hollow fire, they will require to be coated with the prussiate of potash previous to immersion. A very convenient box in which to heat a moderate quantity of small screw dies or screw taps, may be made by welding a plug into the end of a piece of large wrought-iron pipe.

A loose plug will be required for the opposite end of the pipe; it must be the same size as the bore of the pipe, and about 1½ inches in length. Part of the plug must be allowed to project out of the pipe for the convenience of gripping it with the tongs, or tapping it with the hammer when required to be taken out; otherwise, it may be difficult to get it out, especially after it has been luted with loam. The plug will require to be temporarily fastened into its place; this may be done by boring a hole through the pipe and the plug, and driving an iron pin through the two. It will be obvious that when a large quantity of screw dies or screw taps are required to be heated in a box, the box should be larger in proportion to the quantity to be operated upon, and the box will require to be made of plate iron.

After screw dies are hardened, they will require to be brightened and tempered. The tempering may be performed by placing the dies, several at once, upon a hot plate of cast metal; or they may be tempered by placing them upon a piece of bar iron, one end of which must be heated to redness. Those kinds of dies which are used in the screwing machine, and all large screw dies of a similar shape, will require to be placed upon the heated iron, screw part uppermost, in order that the heat may not be too suddenly applied to the cutting part of the dies.

As soon as these kinds of dies are observed to be changing their color, they must be moved to the cooler part of the iron, otherwise the bottom part of the screw part of the dies will be apt to become softer than the top part, and the temper would be unequal. It will sometimes be found necessary, after the dies are removed to the cooler part of the iron, to turn them bottom upward for a few moments, or to

turn them upon their sides, in order to obtain a uniform degree of temper.

Some kinds of screw dies require to be placed upon the hottest part of the iron at first, and as they become heated should be drawn toward the cooler part of the iron. Other kinds of screw dies require to be placed upon the cooler part of the iron at first; and, as they become heated, they require to be drawn toward the hotter part of the iron. This, of course, depends upon the depth of the dies, or the distance between the screw part and the back part of the dies.

The dies must be allowed to remain upon the heated iron until their cutting parts become uniformly changed to a dark straw color; after which they may be cooled in water or oil, or allowed to cool in the air of their own accord, according to circumstances previously explained. The smaller size screw dies may be uniformly tempered, and the heat very gradually applied, by placing them upon a stout piece of cold plate iron, and then placing the plate and dies upon a thick piece of iron heated to a whitish heat. The dies must be turned over occasionally in order to expose all their sides to the heat. As their surfaces become changed to a dark straw color, they may be pushed off the plate into a vessel containing water or oil. If the plate has not become too hot, their places may be filled up with others. If the plate has become too hot, it may be taken off the hot iron and placed upon the anvil face; it will then in a few moments be in a fit state for tempering a second quantity. By putting the plate back into its place (upon the hot iron) a third, and sometimes a fourth quantity, may be tempered without reheating the iron.

When it is required to harden a large quantity of those kinds of screw tools called chasers, they may be placed (several at once, or as many as may be convenient) in the midst of the ignited fuel of an open fire, or they may be placed in the midst of the ignited fuel of a very small hollow fire. The screw end or cutting part of the chasers requires to be heated to a cherry-red heat. The blast, of course, must be sparingly used. When they arrive at the proper heat, they must be drawn out of the fire; but, should there be some in advance of the others, these must be the first to be drawn out, after which the heated end will require to be coated with the prussiate of potash. They must then be returned to the fire for a few minutes, or until they acquire a cherry-red heat, after which they must be immersed in the water and entirely quenched. In order to keep up a continuance of the process, as they are withdrawn their places in the fire must be filled up with others. After the whole of them have been immersed and become cool, they will require to be brightened and tempered. They may be brightened upon a grinding stone or an emery wheel, or by rubbing the top surface with a piece of grinding stone, or by an emery stick, or a piece of emery cloth. After the chasers are brightened they may be placed, several at once, upon a piece of flat bar iron heated to redness. The screw end of the chasers must be allowed to project some distance (about 1¼ inches) over the heated iron, otherwise the heat will be too suddenly applied to the cutting parts of the chasers. As soon as a yellowish white or light straw color appears upon the cutting parts of the chasers, they must be removed from the heat and cooled in water or oil, otherwise the back part of the chasers which was in contact with the heated iron will con-

tinue to supply heat, and the chasers will become too soft. As the chasers are removed from the hot iron, their places can be filled up with others. By having two pieces of iron, one piece in the fire becoming heated whilst the other piece is being used, a continuance of the process may be kept up. After the chasers are taken out of the water or oil, and the top surface ground upon the grinding stone, they are ready for use. Though this method is a very expeditious one for hardening and tempering a large quantity, still it is not absolutely necessary to adopt it with a small quantity, or a single chaser; because they may with care be hardened and tempered equally as well by heating them and partially dipping them into the water and tempering them by the heat at the back part of the chaser, without the use of the hot iron. It will be obvious that, when this method is adopted, a greater portion of the tool will require to be heated, in order that the back part of the chaser may retain sufficient heat to temper the cutting part after it has been immersed into the water.

When this method of partially dipping the chaser is adopted, it will be advisable to put the water in motion previous to dipping the chaser; or, otherwise, when the cutting part of the chaser is beneath the surface of the water, give the chaser a quick movement; this will prevent the water from cooling the steel in a strict line, and guard against water cracks. That part of the chaser which is beneath the surface of the water must be allowed to remain in the water until it becomes quite cool, after which it must be taken out and brightened. In a short time the back part of the chaser will supply sufficient heat to the cutting part to temper it to the desired color. As soon as the proper color appears, the chaser must be entirely quenched; and, when taken out of

the water and ground upon the grinding stone, it will be like those which have been wholly quenched and subsequently tempered on the heated iron, ready for use.

When it is required to harden a screw plate, it may be placed in the midst of the ignited fuel of a very small hollow fire, or among the ignited fuel of an open fire. It will require to be very slowly and uniformly heated to a cherry-red heat; the blast of course must be sparingly used, otherwise it will become crooked. There is no necessity for heating the whole length of the shank or handle; but it is quite necessary to heat a small portion of it, in order to obtain a more uniform heat upon the plate. As soon as the temperature of the plate is sufficient to fuse the prussiate of potash, it must be withdrawn from the fire, and coated with the potash, in a manner similar to other kinds of tools; after which it must be immersed very slowly, endways and perpendicularly, in water. The largest size screw plates will generally keep truer by being immersed edgeways and horizontally in the water. The screw plate must be allowed to remain in the water until it becomes quite cool, after which, when taken out, it will require to be brightened and tempered. It may be tempered by holding it over a piece of flat bar iron (heated to redness) until a dark straw color appears upon its surface; or it may be tempered between two pieces of flat iron heated to redness, and placed a certain distance apart from each other, in order that the heat may not be too suddenly applied; or it may be held in the inside of an iron ring heated to redness; or it may be tempered in a sand bath, provided the temperature of the sand is just sufficient to change it to the proper color—if the sand is hotter than this, there is a great risk of the threads becoming

too soft; or the heat may be applied by any other convenient method, after which the plate will be ready for use.

Screw plates and screw dies are often ruined by being used upon iron and steel rough from the forge, and covered with scales, which, from their hard, gritty nature, grind away the threads. In all cases the rough scale should be removed from the iron or steel, either by the turning tool, file, or grinding stone, previous to screwing it with the screw plate or the dies. It is not an uncommon practice with some workmen, after they have finished forging a piece of iron work, and while the iron is at a red heat, to immerse it in water and partly cool it, with a view of giving the work a cleaner appearance; but this is a very bad custom, especially when the forging requires to be screwed. It very often happens that the iron contains veins of steel, which harden by immersion; and, though the metal may not be so hard as to prevent its being cut with a hard turning tool, still, when it comes to be screwed with the stocks and dies, or with the dies belonging to the screwing machine, or with the screw plates (which tools are always less hard than the turning tools), it will spoil the dies or the screw plates; and because this hard place or places do not happen to be detected when turning the work (on account of using a very hard tool), the steel the dies or screw plate is made of will be thought bad, or badly tempered. The fact is, the work should always be annealed rather than hardened. In all cases when an impure iron is made use of for forgings, and which will subsequently require to be screwed, either with the screw dies or the screw plate, or which may require to be cut with circular cutters or with circular saws, the forgings should always be annealed previous to leaving the smithy. The forgings, of

course, will be the better for being annealed supposing they are to be screwed with the screw tools belonging to the turning lathe; though it is not of so much importance as when they are to be screwed with the dies, or the screw plate, or cut with circular cutters, or circular saws, because the screw tools belonging to the turning lathe can be ground again, provided they chip from being very hard; whereas, the generality of screw dies, screw plates, and circular cutters, and even circular saws, when very hard, and once spoilt, will not admit of being again sharpened, but will be practically useless, until they have been annealed, and cut up again, and subsequently hardened. Annealing makes the iron more uniform in temper, and will save much subsequent trouble; it will greatly facilitate the work when fitting it up.

When it is required to harden a large quantity of stout circular saws at once (for cutting metals), they may be enclosed in a sheet-iron case, or box; they will require to be surrounded on all sides with either wood or animal charcoal. Sufficient space must, of course, be left every way for the expansion of the saws; otherwise they will become buckled in heating. After the saws are enclosed and the box luted with clay or loam, the whole may be placed in a suitable furnace or hollow fire and the saws heated to a cherry-red heat (the fire of course must not be urged). As soon as the whole arrive at the proper uniform temperature, the box must be drawn toward the mouth of the fire, the lid taken off and the saws taken out separately. They may either be taken out of the box with the pliers or by a small rod of iron, having a small hook turned upon one end of it. The saws will require to be immersed edgeways in a trough

containing water, the surface of which must be covered with a film of oil. The oil will float of itself upon the surface of the water and burn upon the saw as it passes through it. The burnt oil forms a coating of coal upon the saw, which protects it from the direct action of the water, and lessens the risk of fracture.

Though saws are the better for being enclosed in a box and surrounded with charcoal when heating them, still, when a single saw is required to be hardened in a hurry, it will be more expeditious to place it upon a piece of cold sheet-iron, and then to heat the iron and the saw in the midst of the ignited fuel of a hollow fire; and when it arrives at the proper temperature, it must be taken off the plate and immersed in the hardening fluid. By placing the saw upon a piece of cold sheet-iron, it causes the heat to be very slowly applied, and it has a tendency to prevent the saw buckling in heating. Oil alone, or oil in which tallow has been dissolved, is sufficient to give the thinnest kinds of saws a sufficient degree of hardness; but those of a medium thickness are the better for being hardened in solid tallow (the saws may be placed separately between two flat lumps of tallow). Tallow differs from oil in the absorption of heat for its fusion; consequently, a more considerable degree of hardness is given to the steel by the tallow than by the oil; besides, it hardens the steel to a greater depth than oil. Very thin blades of steel may be made sufficiently hard for some purposes by heating the blades to a red heat and then placing them between two heavy surface plates; the surface plates will be better if they be smeared with tallow, previous to putting the blade between them. When the saws are removed from the hardening trough, they are generally brit-

tle and warped; consequently, they will require to be tempered and hammered flat. The tempering may be performed in a variety of ways, depending of course upon the size, shape and quantity. Circular saws, which are required for sawing hard substances (such as iron or steel), and which have a round spindle hole, about 1 inch in diameter, in them, will require to be tempered to a light straw color. These may be tempered by first brightening their surfaces, and then placing them upon a piece of hot iron. The piece of iron which will be required for tempering these kinds of saws may be made by the following method. Take a piece of round bar iron, 1 inch in diameter and 8 or 9 inches in length; heat one end of it and hammer it so as to make it fit into the small square hole in the anvil; at the opposite end of this piece of iron, and at about 2 inches from the extreme end, weld a moderate-sized iron collar; the collar should be made of half-round iron, so that it will, after it is welded upon the piece of round bar, form a large lump, the shape of a round ball. The object of this large lump is to retain the heat for a considerable time, so that several of the saws may be tempered before the iron will require to be reheated. If two of these lumps were made, one of them could be in the fire becoming heated, whilst the other lump is being used; so that, if it were necessary, a continuance of the process may be kept up. The object of having this lump the shape of a round ball is that it may not supply the heat too suddenly to the saw. If this lump were made flat, it would supply the heat too suddenly, unless it were used at a very low temperature; it is evident it would not then temper more than one or two of the saws before it would require to be reheated. The object of having this

round lump welded upon a piece of round bar is for the convenience of keeping the lump in position upon the anvil, and to prevent the operator from always being in a stooping position when tempering the saws. The iron being finished, it is now ready to be heated for tempering the saws. The large lump will require to be heated to a red heat, after which the opposite end of the iron must be placed in the hole in the anvil. The saws may now be placed (one at a time) upon the lump; a slow, rotary motion must be given to the saw, by the use of a small stick of wood, in order to equalize the heat. The end of the round bar at the top of the lump will help to supply heat and keep the saw in position whilst it is being turned upon the lump. As soon as a light straw color appears upon the saw, it must be taken off the iron and cooled, either in water or oil; or, if the heat has not been too suddenly applied, the saw may be allowed to cool in the air of its own accord. These kinds of small circular saws are generally, after hardening, convex on one side and concave on the other. This imperfection is owing to the outer part of the saw becoming too small to contain the central part. When the practice of securing the saws upon the spindle by circular plates screwed firmly against each side is adopted, a small degree of regular convexity is not very detrimental, because the plates bring the saw straight; but when they are convex in a greater degree, they will require to be slightly hammered. The outer part of the saw is the part which requires to be hammered, in order to expand the outer part and bring the middle flat.

These kinds of saws may be tempered, and the trouble of brightening their surfaces spared, by smearing them with

oil or tallow and holding them one at a time over a slow clear fire until the oil or tallow begins to smoke, after which the saw must be immersed in oil and partly cooled; it must then be held over the fire the second time, until the oil again begins to smoke. If the saw is immersed in the oil and held over the fire a third time, it will ensure a more regular degree of temper. Care must be taken each time the saw is heated not to raise the temperature beyond that which is necessary to cause the oil to smoke; otherwise the saw will become too soft for the purpose it is intended for—namely, cutting hard substances. By this method the saws acquire the same temper as that which they acquire when tempered to a straw color. A large quantity of these kinds of saws may be tempered more expeditiously by threading them upon a piece of iron wire, and then placing them in a proper vessel, with as much oil or tallow as will cover them (the wire is for convenience in lifting the saws out of the vessel), and then to place the whole over a small clear fire, or over a gas flame, until the oil or tallow begins to smoke, after which the saws must be taken out. They may be then cooled in water or oil, or they may be allowed to become cool in the air. This indicates the same temper as that called a straw color.

Saw blades which are required for sawing wood require to have the greatest amount of elasticity given to them; consequently, after they are hardened, they will require to be tempered to the same temper as that called spring temper. This may be done by exposing the blade, the surface of which has been brightened, to the regulated heat of a plate of metal till the surface has acquired a blue color; or it may be heated in a sand bath heated to the proper tem-

oil or tallow and holding them one at a time over a slow clear fire until the oil or tallow begins to smoke, after which the saw must be immersed in oil and partly cooled; it must then be held over the fire the second time, until the oil again begins to smoke. If the saw is immersed in the oil and held over the fire a third time, it will ensure a more regular degree of temper. Care must be taken each time the saw is heated not to raise the temperature beyond that which is necessary to cause the oil to smoke; otherwise the saw will become too soft for the purpose it is intended for —namely, cutting hard substances. By this method the saws acquire the same temper as that which they acquire when tempered to a straw color. A large quantity of these kinds of saws may be tempered more expeditiously by threading them upon a piece of iron wire, and then placing them in a proper vessel, with as much oil or tallow as will cover them (the wire is for convenience in lifting the saws out of the vessel), and then to place the whole over a small clear fire, or over a gas flame, until the oil or tallow begins to smoke, after which the saws must be taken out. They may be then cooled in water or oil, or they may be allowed to become cool in the air. This indicates the same temper as that called a straw color.

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round lump welded upon a piece of round bar is for the convenience of keeping the lump in position upon the anvil, and to prevent the operator from always being in a stooping position when tempering the saws. The iron being finished, it is now ready to be heated for tempering the saws. The large lump will require to be heated to a red heat, after which the opposite end of the iron must be placed in the hole in the anvil. The saws may now be placed (one at a time) upon the lump; a slow, rotary motion must be given to the saw, by the use of a small stick of wood, in order to equalize the heat. The end of the round bar at the top of the lump will help to supply heat and keep the saw in position whilst it is being turned upon the lump. As soon as a light straw color appears upon the saw, it must be taken off the iron and cooled, either in water or oil; or, if the heat has not been too suddenly applied, the saw may be allowed to cool in the air of its own accord. These kinds of small circular saws are generally, after hardening, convex on one side and concave on the other. This imperfection is owing to the outer part of the saw becoming too small to contain the central part. When the practice of securing the saws upon the spindle by circular plates screwed firmly against each side is adopted, a small degree of regular convexity is not very detrimental, because the plates bring the saw straight; but when they are convex in a greater degree, they will require to be slightly hammered. The outer part of the saw is the part which requires to be hammered, in order to expand the outer part and bring the middle flat.

These kinds of saws may be tempered, and the trouble of brightening their surfaces spared, by smearing them with

perature. To spare the trouble of brightening them, they may, like small circular saws, be smeared with oil or tallow and heated over a clear fire. It is obvious that the softer the steel is intended to be, the more grease must be burnt off; consequently, those saw blades which are required for sawing wood, and which require to be sharpened with the file, will require to be heated till thick vapors are emitted and burn off with a blaze; two or three reheatings, and partly cooling them in oil, when tempering, will, of course, insure a more uniform degree of temper. Saw blades which are required for sawing wood, could, like those intended for sawing metals, be heated and tempered in hot oil; but, perhaps, it would not be very economical. The oil, of course, would require to be heated to a very high degree, in order to impart to the saws a spring temper; so that it is questionable whether the time saved by this method would be sufficient to compensate for the waste of oil, which at this high temperature is considerable; consequently, it becomes those who have such things to temper to adopt those methods which will answer their purpose the best. Saw blades, unless hardened in a current of air, are generally, after hardening, buckled and twisted in various directions; this is caused by an unequal contraction of the blade, and it would be almost, it not quite, impossible to prevent this unequal contraction, when it may arise from so many causes. The metal itself may be unequal in its texture. It may have been rolled at a temperature which was not uniform throughout the mass, or the blade may have been hammered more in one part than another; this would be sufficient, from its unequal density, to cause unequal contraction; or, if the temperature is not uniform throughout the blade when

it is immersed in the hardening fluid, it will cause unequal contraction.

Saw blades which have become buckled and twisted in hardening, will, after they are tempered, require to be hammered flat; this operation requires a considerable amount of care and practice. It is obvious that the blades will require to be hammered at every part except those which are buckled. The hammering draws and expands those parts which are not buckled, and removes the unequal tension which has been caused by the unequal contraction of the blade. The extent to which the blade will require to be hammered, of course, can only be ascertained by experience.

When saw blades are well hammered, and the unequal tension has been removed, they are then flat and more uniformly elastic; but if the crust of the blade be partially or wholly removed by grinding, or in any other manner, the elasticity is proportionately impaired, and to restore the original excellence of this property, the blade will require to be again hammered and afterward blued. Saws require to be made of the best cast-steel, and, like all other kinds of tools, when required for cutting brass, require very sharp cutting edges; they require also to be, in a slight degree, harder for brass and cast-iron than for steel or wrought-iron, otherwise they soon lose their sharp edges.

When it is required to harden a single saw, such as is used for sawing off the ends of wood screws, or for sawing off the ends of small screw bolts, or for occasionally sawing the grooves in the heads of screws, it may be heated to a cherry-red heat, and then placed flatways and horizontally between two lumps of tallow, or it may be pressed edgeways into a single lump of tallow. When it is intended to harden

the saw by this last method, the saw should be slightly hammered at the back previous to heating and hardening it, otherwise the cutting edge will, in hardening, become convex, and the back edge will become concave. If the saw becomes crooked sideways, it may be straightened by slightly hammering it with the peen of a small hammer at the concave side, at the same time pressing with the fingers upon each end of the saw. The saw will be the better for being slightly heated previous to hammering it; it may be heated by placing the back side of it upon a piece of hot iron. If the saw should be found too hard for the purpose it is intended for, the back edge may then be placed upon the hot iron, and the saw tempered to a light straw color.

When it is required to harden a lathe center, it may be heated in an open fire; the tapered part only requires to be heated, and this only to a low red heat; the lowest heat that it will harden at is the most advantageous, as the center is the more likely to keep true, and it will not afterward require to be tempered. It must be immersed endways and perpendicularly in the water; the back end of the center must enter the water foremost; it must be allowed to remain in the water until it becomes cool, after which it is ready for use. Lathe centers for large lathes, on account of the heavy weights they sometimes have to carry, ought always to be made of the most tenacious cast-steel, which ought only to require a low red heat to harden.

When it is required to harden a large or small quantity of fluted or other kinds of reamers, they may be heated in a similar manner to screw taps, either by enclosing them in an iron box, and surrounding them on all sides with carbon,

and placing the whole in a furnace or hollow fire, or by placing them in the midst of the ignited fuel of a small hollow fire. It will sometimes be more advantageous to heat these kinds of articles in red-hot lead, especially when a large quantity requires to be operated upon, because this is a very expeditious method for heating them, and they generally keep truer in heating by being surrounded on all sides with the uniform temperature of the lead, consequently they will keep truer in hardening. The lead, of course, must be heated to a certain temperature suitable to the steel. If the reamers are made of the best cast-steel, the temperature of the lead need not be raised higher than what is necessary to heat the reamers to a cherry-red heat; if the lead is too hot, it will burn the steel, and cause the reamers to be full of very small holes, which, of course, will unfit them for the purpose for which they are intended. If the lead by chance becomes too hot, it may be cooled down to the proper temperature by dipping a piece of cold iron into it.

When it is intended to heat small reamers in red-hot lead, it will be necessary (previous to putting them into the lead), in order to protect them from the direct action of the heat, and to prevent the lead sticking to them, to brush them over with a little soft soap; the largest and middle-size reamers will be the better for being brushed over with black lead, mixed with water, or they may be brushed over with a mixture of lampblack and linseed oil. If the black lead and water is used, it will be well to dry the reamers previous to putting them into the lead, otherwise the dampness may cause the lead to fly, and accidents may happen from it. Whichever method be adopted for applying the heat to reamers, they will require to be heated to a cherry-red heat, after

which they must be immersed separately, endways, perpendicularly (except half-round reamers), and slowly in the water. Half-round reamers are very liable to become crooked, or concave on their round side, owing to the round side being the last to become cool; consequently, they will require to be immersed in the same steady manner as the other kinds, but not so perpendicularly — they will require to have a more horizontal inclination. They may be immersed perpendicularly, provided they are slowly moved horizontally in the water in the direction of the round side, at the same time that they are being immersed endways. It must be borne in mind that red-hot lead will heat the steel much quicker than the ignited fuel of the fire; consequently, when large fluted reamers are heated in lead, the cutting ribs of the reamers will arrive at the proper temperature much sooner than the central parts of the reamers, or before the innermost center becomes at all heated; and if the reamers are immersed in the water the moment the cutting ribs become sufficiently heated (and they may be immersed without fear of breaking them), the central parts of the reamers will remain soft; consequently, if large fluted reamers become crooked in hardening, they may be easily straightened. They may be straightened by laying them upon a block of hard wood, or upon a block of lead, and then putting a piece of round iron (the size of the groove) into the groove at the convex side, and then striking the iron with the hammer. If the reamers be tempered previous to striking them with the hammer, they will straighten the easier. When small fluted reamers are heated in red-hot lead, they become heated through almost instantly they are put into the lead; consequently, it must be obvious that if these become crooked

in hardening, they cannot be straightened in the same manner as the larger sizes; therefore, in order to guard against their becoming crooked, they must be allowed to remain in the heated lead until they become uniformly heated to their innermost center, and then immerse them endways, and perpendicularly, and very slowly in the water, and entirely quench them; and if any of them become crooked, it will be well to soften them again, then straighten and reharden them. Care must of course be taken not to raise the temperature of the lead higher than what is necessary to heat the reamers to the proper temperature suitable for hardening them. The method I have myself sometimes adopted when hardening fluted reamers is this: I have heated them separately in red-hot lead, and then immersed them separately, endways, and perpendicularly, in the water, having the water of a suitable depth, so that when a reamer was immersed, and the extreme end of it made to touch the bottom of the tank, and then withdrawn, it would harden the cutting edges of the reamer, and leave sufficient heat in the central part, so that the reamer would, if it were crooked, admit of being straightened, either by placing it between the centers of a turning lathe, and striking it upon the convex side with a small wooden mallet, or, by placing it upon a block of hard wood, or a block of lead, and striking upon the convex side with the mallet. As this method requires a great amount of experience and dexterity, and as there is great risk of the reamers breaking when they are struck with the mallet, especially if they be allowed to become too cool previous to striking, it will be well, perhaps, for the operator (in order to avoid any considerable obstacle) to adopt the method previously explained, that of immersing them end-

ways, perpendicularly, and slowly in the water, and entirely quenching them.

Reamers after they are hardened will require to be tempered, which may be done by adopting similar methods to those to be adopted for tempering screw taps. Fluted reamers will require to be tempered to a yellowish white, or light straw color; six and eight-sided reamers will also require to be tempered to a light straw color; square, and triangular, and half-round reamers will require to be tempered to a dark straw color. The reason why square, and triangular, and half-round reamers require to be reduced lower in temper than the other kinds is, that they take hold of the work so deeply that they are very liable to break by the force requisite to turn them round. Six and eight-sided, and square and half-round reamers, which have become slightly crooked in hardening, may be straightened by screwing a chipping hammer (flat face uppermost) between the jaws of a pair of vise; the convex side of the reamer may then be laid upon the hammer face, while the concave side is slightly hammered with the sharp peen of a small hammer, at the same time pressing with the fingers upon each end of the reamer. If the reamers (previous to hammering) be slightly heated, they will straighten the easier, and be less liable to break.

Small drills, gouge bits, center bits, countersinks, gimlets, bradawls, or sprig bits, etc., may be expeditiously hardened by dipping their cutting parts into red-hot lead, and then cooling them in water. When it is intended to dip several of any of these kinds of articles at once into red-hot lead, it will be necessary to have a pair of tongs with long jaws for gripping the articles. One of the jaws of the tongs will require to be made hollow inside, and the

other jaw made flat; the hollow jaw is for convenience—for binding a piece of wood into it—so that if the articles should happen to be of an unequal thickness, the tongs may grip them all, as the most prominent parts of them will sink into the wood. When the wood becomes too much worn, it may be replaced by another piece. Any quantity of these articles may be heated as expeditiously as a single article, if there be sufficient lead. Gouge bits, gimlets, bradawls, or sprig bits, will require to be tempered after they are hardened. They may be tempered by placing them upon a piece of hot iron, and heating them until a blue color appears upon their surfaces, and then pushing them off the hot iron into a vessel containing cold oil; or, if the heat has not been too suddenly applied, they may be allowed to become cool in the air of their own accord. A large quantity may be tempered at once by placing them in a proper vessel with as much oil or tallow as will cover them, and then placing the whole over a small fire, and slowly heating the oil until it will take fire if a light be presented to it, but not so hot as to burn when the light is withdrawn. The articles may then be lifted out of the oil (that is, providing the vessel is furnished with a false bottom), or the whole may be tipped out of the vessel upon a thin sheet of iron which is slightly curved and placed in a slanting position, with a vessel placed at the bottom to catch the oil; the articles may then be allowed to drain and become cool of their own accord; they will then be the same temper as if their surfaces were blued upon hot iron.

Center bits and countersinks for cutting wood require to be tempered to a purple color. The heat may be applied to these either by a piece of flat bar iron, or by an iron ring

heated to redness, or they may be placed in a proper vessel containing oil or tallow, and then placed over a small fire, and the whole slowly heated until the oil yields a thick black smoke, but not so hot as to take fire if a light be presented to it. The articles must then be taken out of the oil, and allowed to become cool; they will then be the same temper as if their surfaces were changed to a purple color upon hot iron.

Red-hot lead is an excellent thing in which to heat any long plate of steel that requires hardening only on one edge, for it need not be heated in any other part but that which is required hard, and it will then keep straight in hardening; at least, it will keep very much truer than if it were heated in the midst of the ignited fuel of the fire.

If a long steel plate which requires to be hardened only on one edge be heated in a furnace, or in the midst of the ignited fuel of a hollow or open fire, and then the whole body of it immersed in the water, it will become very much twisted and warped, and will cause a deal of trouble to set it straight again, even though the steel be tempered previous to being hammered, especially to those who are unacquainted with the way of hammering and setting steel plates in a hardened state. If the plate be heated throughout its body, and if only one edge of it (the edge which is required hard) be immersed in the water, or, in other words, if the plate be only partially immersed, the plate will become, in a great degree, concave on one edge and convex on the other. The edge of the plate which goes in the water becomes convex, and the edge which does not enter the water becomes concave. This is owing to that part of the plate which is below the surface of the water contracting and becoming shorter by the loss of heat, and compressing the red-hot

part of the plate which is above the surface of the water into a denser state; moreover, after that part of the plate which was below the surface of the water has become quite cool, it will be in a slight degree longer than what it was when in its soft state, consequently this has a tendency to push the red-hot part of the plate round, and thereby helping to cause the uppermost edge of the plate to become concave.

After the whole body of the plate has become cool, the hardened part, as well as the soft part of the plate, will sometimes be shorter than what it was previous to hardening, even though the hardened part did expand longer in hardening. This is caused by the soft part of the plate contracting by the loss of heat after the hardened part has become cool, and thereby compressing the hardened part into a denser state. If red-hot lead is used as a source of heat, and the edge of the plate only (which is required hard) be put into the lead, it is obvious that the other part of the plate will remain cool; consequently, when the plate is entirely immersed in water, the hot part of the plate will not act with sufficient force to alter the cool part, consequently the cool part of the plate tends to keep the hardened part true. It may be inquired, if the part which goes in the lead expands longer in hardening, and is not able to act with sufficient force to compress the cool part, will not the hardened part become twisted and buckled? The answer to this is: it will not become twisted or buckled by the expansion (though it may become crooked in a slight degree by the unequal hammering, or the unequal density of the steel), because the heated part of the plate has been compressed by the cool part during the time it was expanded

by the heat, consequently the expansion will generally be about equal to the compression, and the plate will be about the same dimensions that it was previous to hardening.

Should the hardened part of the plate happen to become in a slight degree longer than what it was previous to hardening, it is a proof that the expansion predominates over the compression; if, on the contrary, it becomes shorter, it is a proof that the compression predominates over the expansion.

When it is intended to heat articles in red-hot lead, they ought not to be plunged too quickly into the lead; plunging cold steel too suddenly into red-hot lead has a tendency to cause it to become crooked, in a similar manner as red-hot steel becomes crooked when it is plunged too suddenly into cold water.

All articles which are heated in red-hot lead should be slightly moved up and down in the lead during the time they are becoming heated, otherwise the heat will be apt to terminate in a strict line, and will probably cause them to crack when they are immersed in the water.

A very good vessel in which to heat the lead when one edge of a long plate is required to be heated, is made by taking a piece of 3-inch angle iron, a few inches longer than the plate to be hardened, and slitting and turning, and welding each end of the angle iron so as to form a kind of trough. A long fire will be required for heating the angle iron and the lead. A fire of any length may be made by taking a piece of wrought-iron pipe, and boring some holes into it in the direction of its length. The holes will require to be about 5/8 of an inch in diameter, and about 3 inches apart; one end of the pipe must then be inserted into the aperture of the tuyere. A row of bricks

must be placed on each side of the pipe, at a suitable distance from it, so as to leave room for the fuel and the angle iron between the bricks. The pipe will require to be covered over with loam or fire clay, in order to keep it from burning; previous to covering the pipe over, each hole should be stopped with a piece of wood, so that the loam may not get into the pipe, or stop up the holes in the pipe; after the covering up of the pipe is completed, the pieces of wood may then be pulled out of the holes, and the fire lighted. The fire will burn with more regularity if the first three or four holes (at the end of the pipe which enters the tuyere) be a little larger than the others, as the blast is always strongest at the far end of the pipe. A loose plug will, of course, be required for the far end of the pipe to stop the blast; and if, at any time, the pipe becomes stopped by the ashes falling through the holes of the pipe, the loose plug may be taken out, and the ashes blown out of the pipe; the plug may then be put back into its place. If more durable things than the angle iron and pipe be required, a long fire tile may be chipped out to the proper shape, and made to answer the purpose, and a small special furnace constructed for heating it. A pot for melting a small quantity of lead may be made by welding a plug into one end of a piece of wrought-iron pipe; but this is not very durable, as the high temperature of the lead will soon cause it to burn into holes, and allow the lead to run out into the fire.

When a more durable thing than the wrought-iron pipe is required, and a larger quantity of lead requires heating, a crucible similar to those used in brass foundries will be suitable. Crucibles containing a large quantity of lead cannot conveniently be heated in a common smith's fire; con-

sequently, a suitable furnace must be constructed for the purpose. When it is necessary to heat the lead in a crucible, it should be made red hot previous to putting the lead into it; and, in heating the crucible, the same plan must be adopted as that which is generally adopted in brass foundries; namely, putting the crucible in the fire with its mouth downward, in order that the heat may act upon the inside and outside of the crucible at the same time, and so cause a more uniform expansion of the crucible, and lessen the risk of its cracking. The crucible need not be reversed until it has become red hot; then it will be ready to receive the lead. If the crucible be put in the fire bottom downward, the heat for a time would only act upon the outside; consequently, it would cause an unequal expansion, and increase the risk of its cracking.

Another thing to be observed is that the surface of lead when melted in open vessels becomes quickly covered with a skin, or pellicle. This is occasioned by the action of the oxygen of the atmosphere, the activity of which soon causes the skin to increase in thickness, and wastes the lead so fast that it becomes an object of importance to those who use much lead to check its formation, or convert it when formed into the metallic state again. Charcoal, or fatty substances, assisted by sufficient heat, convert this dross, or oxide, into metal again; but if a covering of charcoal or cinders be kept on the surface of the melted lead, the oxide will not form. When it is allowed to form, it not only wastes the lead, but is a great obstruction in getting the articles in and out of the lead.

In a former part of this work it has been recommended to allow steel, when heating for hardening (in order to assist the

process), ample time to soak, and become uniformly heated to its innermost center. In this place (on the subject of heating steel in red-hot lead) it is stated that large fluted reamers may be immersed in the water, without fear of breaking them, immediately their cutting ribs or edges become uniformly heated to the proper temperature suitable for hardening them, without waiting for the central steel to become heated. As this will be probably noticed by some persons who may not perhaps give it sufficient thought to ascertain the true meaning of it, it will then appear to them that one part of the work is in contradiction to the other part; consequently, I have thought it necessary in this place to give an explanation to it so as to prevent the reader misunderstanding it. In the first place it will be necessary to repeat that red-hot lead will heat steel much quicker than the ignited fuel of the fire; consequently, when such an article as a large fluted reamer is dipped into the red-hot lead, the surface steel will become uniformly heated before the central steel has acquired sufficient heat to cause it to expand (at least from the short time the reamer is in the lead, the central steel can only become expanded in a very small degree); consequently, when the reamer is immersed in the water, the surface steel, in cooling, has not to compress the central steel, neither has the central steel to contract after the outer crust is fixed; consequently, a large fluted reamer may be immersed into the water (without risk of breaking it) immediately the cutting ribs arrive at the proper temperature suitable for hardening them. If the surface steel of any article, when placed in a hollow or open fire, could be uniformly heated without heating or expanding the central steel, there would be no necessity for allowing the steel to soak or be-

come uniformly heated to its innermost center; but as the surface steel cannot, in a hollow or open fire, be uniformly heated without causing the central steel to become heated and expanded also, it becomes then quite necessary to heat the central steel to the same temperature as the surface steel, in order that the central steel may admit of being compressed by the surface steel when it is immersed in the water. When the central steel of any article becomes heated and expanded, and not sufficiently softened to admit of being compressed by the surface steel (when becoming cool), it will have a tendency to hold the surface steel in such a state of tension that it will sometimes cause it to crack in several places, and the surface steel will sometimes shell off in flakes; consequently, it must be seen that if the central steel is heated at all, it is requisite to heat it uniformly with the surface steel; it will then lessen the risk of its breaking in hardening. For further information upon this subject, I must refer the reader to the chapter upon the expansion and contraction of steel.

When it is required to harden large or small drifts in large or small quantities, they may be heated in a similar manner as screw taps, either by enclosing them in an iron box and surrounding them on all sides with carbon, and placing the whole in a furnace or hollow fire, or by placing them in the midst of the ignited fuel of a hollow fire. Whichever method be adopted, they will require to be uniformly heated to a cherry-red heat. When they arrive at the proper heat, they will require to be immersed, separately, endways, perpendicularly, and slowly, in the water and entirely quenched. After the drifts have become quite cool, and been taken out of the water, they will require to be

brightened and tempered; they may be tempered by adopting similar methods to those which are to be adopted for tempering screw taps. Drifts will require to be tempered to a brown color.

When it is required to harden a quantity of large common drills, and which have been allowed to become quite cool after having been forged, they may be placed, several at once, or as many as convenient, in the midst of the ignited fuel of a very small hollow fire, or they may be heated in an open fire, taking care to keep their points out of the hottest part of the fire at first, and gradually drawing their points toward the hotter part of the fire as the upper parts become heated. A considerable portion of the drill will require to be heated to a cherry-red heat. The blast, of course, must be sparingly used. When the drills arrive at the proper heat, they must be taken out of the fire separately. Those in advance of the others must be the first to be taken out; a part of the heated portion of the drill must then be immersed in the water. It must not be forgotten that it is requisite to put the water in motion previous to dipping the point of the drill into the water, or otherwise, to give the drill a vertical, or other movement, immediately it arrives to the proper depth in the water. That part of the drill which is below the surface of the water must be allowed to remain in until it becomes quite cool, after which it must be taken out, and the cutting part brightened, which may be done by rubbing the surface with a piece of grindstone, or with an emery stick, or with a piece of emery cloth. The drill may then be laid upon the anvil, or any other suitable place, whilst another is drawn out of the fire and treated in a similar manner. The heated portion of the

drills which were not immersed in the water will then continue to supply the heat to temper the cutting parts of the drills. After the second drill has been immersed, it may be placed alongside the first drill, and another drill withdrawn from the fire, and so on, until all that have been heated have been immersed. The hardener must, of course (during the time he is drawing the drills out of the fire and dipping them into the water), have his attention upon those he has placed upon the anvil, so that he may see when the cutting parts arrive at the proper temper; as soon as a uniform dark straw color appears upon the cutting parts of the drills, they must be instantly cooled in the usual manner, otherwise the upper part of the drills may continue to supply heat, and the cutting parts will become too soft. Should it happen that the heat at the back part of any of the drills is insufficient to temper the cutting part, it will be advisable, in order to complete the tempering, to hold the drill for a few moments in a gas flame, if the gas is lighted; or it may be placed upon a piece of hot iron, if there is a piece of hot iron ready at hand; or a few hot ashes may be drawn out of the center of the fire, and the drill held over them. All drills which are intended to bore holes less than ¼ of an inch (and when a quantity are required to be hardened) must not, like the larger kinds, be heated and partially immersed; but their cutting parts only should be heated to a cherry-red heat, and the drills wholly immersed and entirely quenched. They may subsequently be tempered, by first brightening their cutting parts, and then placing them several at once upon a piece of bar iron heated to redness. Their cutting parts must be allowed to project some distance over the heated iron, otherwise the heat will be too suddenly applied.

As soon as a dark straw color appears upon their cutting parts, they must be cooled in the usual manner.

Miniature drills, such as those used by clock makers and others, cannot conveniently be heated in the midst of the ignited fuel of the fire; though some of them may be heated in charcoal dust, heated to a red heat. These small drills are generally heated in a gas flame, or in the flame of a candle; they are hardened by plunging suddenly their heated points into a lump of tallow or into the grease of the candle. They are tempered, if found too hard, by taking a little of the tallow upon their points, and then placing them in the flame at a short distance above the point, and holding them there until the tallow upon the point begins to smoke; the cutting part of the drill is then of the same temper as if it were brightened and tempered to a straw color. By any of the methods just explained, the cutting parts of the drills are tempered to a straw color, while the rest is not higher than blue, so that the liability of their breaking, when in use, is greatly diminished.

It has previously been stated that chipping chisels will be the better, if the hammering (when forging them) be continued until the cutting part becomes nearly cool; and, perhaps, it will not be amiss to state here that it is better to harden and temper them after being forged, and while the part above the cutting edge is in a red-hot state, than to allow them to become quite cool, and then to reheat them for hardening. The reason for this is, greater care is required to heat them properly after they have become quite cool; consequently, there is greater risk of the effect of the hammering being taken off again.

When a large quantity of chipping chisels have been forged, and have been allowed to become quite cool, and which may require to be hardened and tempered, similar methods must then be adopted as those which are to be adopted for hardening and tempering the largest kinds of common drills, with the exception that the chisels will require to be tempered to a violet color, that is if they are required for chipping metals. If the chisels are required for chipping stone, they will require to be tempered to a purple color. The force required for chipping stone being less than for metals, it is obvious that the chisels are less liable to break; consequently (in order to prevent them wearing away so fast), they may with safety be left in a slight degree harder.

When it is required to harden those kinds of small chipping chisels which are used for chipping the delicate kinds of work, they must not, like the larger kinds, be heated and partly immersed, but their cutting part only should be heated to a cherry-red heat. They should then be wholly immersed, and entirely quenched. They may subsequently be tempered, by first brightening their cutting part, and then placing them, several at once, upon a piece of bar iron heated to redness. As soon as their cutting part becomes changed to a violet color, they must be instantly cooled in the usual manner.

When a common turning tool is required extraordinarily hard, for cutting very hard cast-iron, it will be necessary, in the first place, to heat the tool to a red heat, and then give it a judicious hammering until it becomes nearly cool, after which it will be necessary to heat some lead to a bright red heat; a small quantity of charcoal dust must be placed upon

the surface of the heated lead to prevent oxidation. During the time the lead is becoming heated, the cutting part of the tool should be heated to a low red heat in an open fire. After the lead has become heated to a bright red heat, and the cutting part of the tool to a low red heat, the tool must be drawn out of the fire, and while it is at a red heat the scale must be removed with the file; the cutting part of the tool must then, as soon after filing as possible, be put into the heated lead. It must be allowed to remain in the lead until it becomes heated to the same temperature as the lead—a bright red heat; after which it must be taken out of the lead and instantly plunged into a bucket of pure cold water, and a rapid movement given to it, and entirely quenched; after which, when taken out of the water and ground upon the grinding stone, it is ready for use. By this method the steel acquires a greater degree of hardness than will be readily imagined by those who have never tried it.

When it is required to harden small spiral springs which are made of steel wire, or springs for locks, or any of the other kinds of slight springs, they will require to be uniformly heated to a cherry-red heat, and then immersed in cold oil (not oil which has been long in use and become thick), and entirely quenched. Springs of a medium thickness will be the better for being cooled in water, the water being previously heated to about 60 degrees of heat, and the surface of which should be covered with a film of oil. The thickest kinds of springs will be the better for being cooled in pure water heated to about 70 degrees of heat. Springs require to have the greatest amount of elasticity given to them; consequently, they will, after they are hardened, require to be tempered. They may be tempered separately,

by smearing them over with oil or tallow, and then holding them over a clear fire, or in a hollow fire, or in the inside of a piece of large iron pipe inserted in the midst of the ignited fuel of an open fire, and uniformly heating them until a white flame burns upon them, or, in other words, until the grease burns off with a blaze. If it is a spiral spring (or any other kind of spring which is not thicker at the ends than at the central part) which is being tempered, and which is shorter in its length than the length of the fire, it will be very apt to become heated at the extreme ends first; consequently, as soon as the two ends arrive at the proper temperature (which is known by the grease taking fire), the spring must be immersed in oil; it must not be entirely quenched, but must be taken out of the oil again immediately, and then again exposed to heat. If the oil upon the ends takes fire again sooner than the oil upon the middle part of the spring, it must then be immersed again in oil, and then again exposed to heat, and so on until the oil burns uniformly upon all parts; otherwise the spring cannot acquire a uniform temper. After the spring has become uniformly heated to the proper temperature, and the oil burns uniformly upon it, it must then be again immersed in oil, then taken out again immediately, and allowed to become cool in the air of its own accord. It will then be fit for use. All kinds of springs, whatever their shape, or whatever their size, may be tempered perfectly by this method. It must be borne in mind that there is but one certain temper which gives to steel its greatest amount of elasticity; consequently, the stiffness or pliability of springs must be regulated by the substance and shape of the steel from which they are made. A very convenient way of tempering a large quantity of

small springs at once (they must, of course, be previously hardened), and of heating them uniformly, no matter how irregular their shape, provided the heat is not too suddenly applied, is to bind a quantity of them together with a piece of iron binding wire, and then to put them into a suitable vessel with as much oil or tallow as will cover them. Then place them over a small clear fire, and slowly heat the whole. Just as the oil begins to boil the springs must be lifted out, when a white flame will burn uniformly upon the whole of them; they must then be immersed into cold oil—they need not be entirely quenched, but they may be taken out of the oil again immediately, and allowed to become cool in the air of their own accord, and when cool, they will be like those which have been blazed off separately over the fire, and fit for use. A separate spring may be attached to a separate piece of wire, which may be lifted out of the oil, occasionally, to ascertain when the whole is at a proper heat, which is known by the white color of the flame upon the spring.

Large springs may be tempered by this method, but the time saved with large springs will not be sufficient to compensate for the waste of oil; consequently, it will be more economical to temper the largest springs by blazing over the fire.

It will be well for those who are not accustomed to the operation, before attempting to boil a large quantity of springs, to boil a single one in a small quantity of oil, and so make themselves acquainted with the proper temperature of the oil, and the proper temper of the spring.

I will now bring this chapter to a conclusion, not because I have no more to say, but because I do not think it necessary to say more; but I may add that the hardness of

cutting tools and the angles forming their edges must be varied according to the strength and hardness of the material to be worked. The harder materials require tools with more obtuse-angled edges, and no cutting tool will act upon a substance harder than itself.

The number of turns which the mandrel of the lathe ought to make in a given time must also be varied according to the strength and hardness of the material to be worked. The velocity of rotation for wood can scarcely be too swift; it must be rather slow for lead, brass, copper, gun metal and bell metal; still slower for ordinary cast-iron, forged iron and steel, and slowest of all for tempered steel and chilled cast-iron, or, in other words, for cast-iron which has been cast in iron molds, or other good conductors of heat.

The reason for these limits is that a certain amount of time, varying with the material, is requisite for the act of cutting to take place, and that the tools, if much heated, will instantly become soft and cease to cut.

# Self-hardening Steel

The alloy steels derive their peculiar properties from the addition of certain elements or compounds of the metal group, as tungsten (wolfram), chromium, molybdenum, nickel and manganese, the two latter, however, when used as alloys, imparting conditions which have thus far excluded nickel and manganese steel from the self-hardening tool steel class.

Self-hardening steel finds its most valuable uses in heavy roughing work where time saved is the main factor to be considered, its peculiar properties enabling it to hold a cutting edge at speeds which would draw the temper all out of carbon steel. For this reason it has come into general use in shops where machine tools are pushed to their utmost capacity.

Owing to the difficulty of annealing and machining self-hardening steel its use was at first confined to simple forms, such as lathe and planer tools which could be forged to shape and ground on an emery wheel or grindstone, and to nail dies and knives and similar purposes; afterwards it was successfully applied to boring bar cutters, milling cutter blades, etc.

A process of annealing has since been perfected which admits of this steel being readily machined to any shape. All kinds of cutters are now made from it, these when finished being merely reheated and laid down to cool; a simple process which eliminates the danger of cracking or warping to which all complicated shapes are exposed when hardened in the bath.

The heat treatment applicable to self-hardening steel varies according to the variety or to the particular element which is dominant in it.

Several modes of "special treatment" have been discovered and applied to self-hardening steel tools, and have greatly added to their endurance, but as knowledge of these has not yet been given to the public, allusion in this article will be made only to general treatment.

To break self hardening steel into lengths for tools, the piece should be carefully heated to a uniform, bright red and cut with a sharp chisel nearly or quite through, or nicked all around while hot and broken off cold.

The heating for forging should be done in a pure fire: sound charcoal or coke in a bed of generous proportions if the heating is to be done on the forge, and coke or gas if in a furnace, will be found to be advantageous. Fine steel should never be heated in green fires. If coal must be used, the impurities should be burned out before putting in the steel.

Where the heating is done in the open fire, that portion of the piece which is to form the cutting end,—if an oblong shape,—should, when first put in, extend a few inches beyond the heart of the fire in order that the heat may be taken up by the body of the piece and be carried by conduction slowly to the projecting end, which should be gradually drawn into the fire.

The heating should be slow and the blast as gentle as possible. The piece should be turned from time to time until the portion to be forged, and the adjacent parts, are brought up to a full, bright red heat; then it should be forged to the required shape.

The force of the blows and the weight of the hammer employed in forging should be in accordance with the size of the piece operated upon. Self-hardening steel is more dense, less plastic and less malleable than carbon steel, and

cannot be shaped as readily. A large section requires a heavy hammer that will act upon the entire mass, as too light a hammer will draw away the surface from the center and produce a rupture. On the other hand a very heavy hammer on a small piece will crush or break the steel.

Before the steel loses its malleability, as it will to a great extent upon reaching a dark red, it should be reheated, and the heating should be repeated as often as may be necessary until the forging is completed.

It is important that during the entire work the heat of the piece should be maintained as nearly as possible at one uniform temperature; especial care should be taken to avoid forging below a dark red; if forged too cold the steel will be injured.

After the forging work is completed the piece should be replaced in the fire with the blast off, and brought to a uniform bright red color. As soon as this condition is attained fully, it should be laid down to cool in a dry place free from draughts. Water should not touch it at any stage. When cold, if the shape admits of so doing, it can be ground to an edge.

Some kinds of self-hardening steel are improved in their cutting qualities by being cooled in an air blast; others work better if cooled more slowly, and some require to be cooled in such a way as to partially anneal them.

If the last reheating has been done properly, the piece will be not only hardened but tempered, since the uniformity of the heat takes out the strains put in by forging, and the gradual cooling reduces the brittleness. The last heat is in reality an equalizing heat producing the same effect as in the tempering fire.

If, however, the piece still appears to be brittle, it may be "tempered" by being again heated carefully and uniformly to a bright red, as before, and then cooled slowly in the ashes on the forge until it reaches a dull red, when the cooling may be completed in the air or in an air blast.

One mode of full annealing is accomplished by heating in a furnace or muffle to a low red, maintaining the temperature uniformly for a period as long in some instances as forty-eight hours, and then letting the steel cool slowly, covered up from the air.

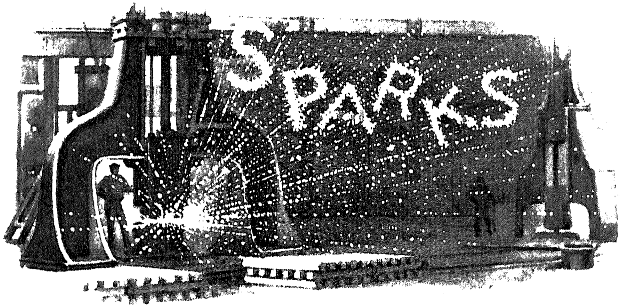
The operation is expensive and tedious, however, and had best be relegated to the steel maker.

There are brands of steel on the market which partake of the nature of self-hardening steel, yet can be hardened like carbon steel if the heating is carefully done.

Instructions for working such steel are generally given on the labels, but in the absence of specific directions this semi-self-hardening steel should be forged in the manner described for self-hardening steel, but at a slightly lower heat, and the final equalizing heat should not exceed a low red, which should be perfectly even.

At this temperature the piece may be quenched in heavy thick oil and need not be drawn. Some kinds may even be plunged into a water bath.

If the heating is carefully done the tool may be used at full hardness.




Overheated steel tells its own story.

A high heat opens the grain of steel and prevents refining.

Cast-steel properly hardened is invariably refined thereby.

The temper of steel is regulated by percentage of carbon.

The iron used in making steel determines its quality.

Consumers of steel should be guided by makers' advices.

Sulphur is an enemy to steel.

Good fuel is essential to best results in working steel.

Charcoal, from sound wood, is the king of fuels.

Avoid exposing hot steel to draughts of air.

Pure water is a good hardening medium.

Cherry red is a safe heat for steel.

Nick cold steel with sharp chisels.

A good softening heat, for forging, can be safely used if proper precautions are observed.

The lead screws of lathes are often responsible for inaccuracies in the threads of taps.

Large pieces may often be protected in heating by being covered with a coating of dry clay.

No annealing is better than over-annealing.

Be sparing of the blast.

Time and care are necessary in the treatment of steel.

Burnt steel is disintegrated steel.

Properly constructed furnaces will pay for themselves in the value of tools which will be saved by their use.

"Soaking," or long continued heats, even if low, are injurious to steel.

It requires a high order of talent to treat high-grade steel successfully.

In heating for hardening, great care should be taken with irregular shapes that no part of the piece be too hot.

Steel which has been annealed at a high heat will not harden on the surface.

A low red heat will anneal steel thoroughly.

Do not try to harden steel that has been annealed, before taking off the surface.

He is a good steel worker who NEVER spoilt a piece of steel.

Do not be deceived by nostrums for restoring burnt steel.

The peculiarities and proper treatment of steel are studies for a lifetime.

Benjamin Huntsman invented the cast-steel process in 1770.

Crucible cast-steel is recognized the world over as the best steel.

Low-priced steel may be very dear steel.

Steel is mercurial and delicately responsive to heat; its records appear in its own structure.

The last age: the age of steel.

Dirty, slack fires put dirty sulphurous oxides on steel.

The hardening heat varies with each temper of steel, and the only safe course is to harden at the lowest heat that, on trial, is found to give the required hardness.

Hardening cracks are more often the result of uneven heating than of defect in steel.

Tool hardeners do not always realize what a slight addition of heat it takes to raise the grain beyond the refining point and create a weak condition.

Heat steel slowly, but do not run to the other extreme by taking too much time in heating.

Uneven heat, too high heat, and heat too long continued, are responsible for many errors.

Always harden on an ascending heat; never on a descending heat.

Large baths are always safer than small ones.

Large centers in taps and reamers are a cause of cracks; close them up.

Clean coke is by many considered preferable to charcoal for heating steel to forge, or harden, because it makes a more even fire.

There is no other way to prevent slender taps, reamers and twist drills from springing, than to heat them carefully. Even then some will come out curved, but they can be straightened while the temper is running.

Boring holes too near the outside of some articles will oftentimes cause the article to crack at the hole.

Sharp internal angles are unfavorable to the strength of articles; and any description of sharp angles is unfavorable in the hardening process.

Cutters used for cutting soft substances, such as brass and copper, require to have their teeth very sharp, and to be made very hard. The teeth also require to be cut much coarser than for iron or steel.

Generally speaking, in dipping articles for hardening which are of unequal thickness, the thick part should enter the bath first.

To insure even hardening, take off plenty of the surface, heat evenly and quench in a large bath.

When a bright surface is hardened, there is more danger of cracking than where the piece is protected by its coating of oxide of iron or scale.

Avoid heating a piece to a strict line for hardening; likewise avoid dipping to a strict line.

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